TECHNICAL REPORT 3092
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Demonstration of Low Impact Development (LID) to Mitigate Stormwater Metal Contaminants in Navy Commercial Areas

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ADMINISTRATIVE INFORMATION

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EXECUTIVE SUMMARY

This report describes an evaluation of the effectiveness of using low impact development (LID) to mitigate stormwater runoff and metal contaminants from Navy commercial areas. The project was conducted at Naval Base San Diego (NBSD) between 2014 and 2017. The work was performed under Project 497 of the Navy's Environmental Sustainability Development to Integration program. The demonstration was completed in response to the need for methods to control stormwater runoff in operational and non-industrial areas of Navy bases requested by Naval Facilities Command Southwest and Northwest Environmental. The NBSD site was chosen for demonstration because it is subject to regulations of stormwater copper, lead, and zinc discharges under its National Pollutant Discharge Elimination System permit and a Total Maximum Daily Load (TMDL) requirement.

The main goal of the demonstration was to validate the effectiveness of LID in reducing stormwater flow and metal concentrations from Navy commercial areas. The results of the demonstration are expected to provide broad applicability across the Navy because these areas are a common land use at military bases across the nation. While LID technologies are widely implemented, they have rarely been evaluated for their effectiveness at Navy facilities, particularly for metal contaminants.

The technical approach was to retrofit two LID technologies in the commercial land use portion of NBSD and compare the volume and contaminant concentrations in stormwater runoff discharging from the LID technologies to the volume and concentrations discharging from non-LID portions of the drainage. The demonstration outcomes were also evaluated against regulatory limits specific to the site and to their predicted effectiveness. The demonstration approach included five major components including: engagement with base personnel and approval, site selection, technology selection, buildout, and monitoring.

The project demonstration required approval by the base Commanding Officer. To that end, the project personnel engaged with base environmental and Naval Facilities Engineering Command Southwest (NAVFACSW) staff to gain acceptance of the concepts and final design, and promote the technology demonstration up the chain of command. This effort was ultimately successful, with approval by the Commanding Officer in July 2015.

A full evaluation of the NBSD commercial area was conducted by SSC Pacific staff together with staff from the Low Impact Development Center, Inc. (LID Center) of Beltsville, MD and their subcontractors. The team reviewed numerous maps, photos, documents, and reports, as well as conducted a site visit to locate and assess stormwater drainage structures for location, size, and elevations. The team selected potential sites for demonstration based on a combination of quantitative factors such as physical features, drainage characteristics, and costs and qualitative factors based on the experience of the project team.

The team also evaluated the drainage characteristics and potential performance for a range of LID technologies using the Windows Source Loading and Management Model (WinSLAMM) that had recently been modified, calibrated, and applied at Navy facilities. The effort focused on the use of bioretention and media-based technologies because of their proven reliability, regulatory acceptance, and effectiveness at treating metals. The final technology selection was based on the site down-selection process, outcomes of the performance modeling, and on meeting a list of key criteria related to bioretention media-based management practices and compliance with Navy facilities LID criteria.

Two technologies were briefed to the Commanding Officer for approval as described above. These included a biofiltration cell behind the Commissary that was approximately 400 ft^2 in size that drained an area of 0.38 acres and a 2800 ft^2 area of permeable pavers in front of the Commissary.

The inclusion of a permeable paver LID technology was made during the final approval process to mitigate the loss of parking spaces that would accompany a second biofiltration cell technology.

Site approvals and the construction contracting process were facilitated by the Naval Base Facilities Engineer and Acquisition Division. Construction began in February 2016 and was completed in July 2016. Stormwater monitoring began in November 2016 and continued through February 2017.

A total of 13 storms were monitored for flow, five of which were also monitored for chemistry by collecting flow-weighted composite water samples that generated event mean concentration (EMC) data. The monitored rain events ranged in size from 0.15 to 2.41 in, covering the full range of storms observed in San Diego. Four of the five storms monitored for chemistry represented true EMC data and were used for the evaluation of LID effectiveness.

Effectiveness of the two LID technologies was evaluated primarily by comparing stormwater runoff volume and concentrations from the two sites to runoff from adjacent non-LID reference sites. An additional evaluation compared runoff concentrations from the LID technologies to stormwater action limits regulated under the TMDL. The observed LID technology effectiveness was also evaluated against the levels predicted in the technology selection and modeling process.

The results of the demonstration showed that the Paver LID technology was 100% effective at reducing runoff and contaminant loading under rainfall conditions ranging up to the 99th percentile storm event. Since there was no discharge out of the Paver LID site it is not known to what extent the technology had in reducing metal concentrations.

The results also showed that the Biofiltration LID technology was also effective at reducing the mass load of contaminants. The overall load reduction was ~68% for storms ranging up to the 99th percentile storm. The results were primarily from stormwater flow volume reduction out of the technology that averaged 57%. The load reduction was rainfall dependent ranging from 100% effective for rainfall events less than 0.2 in, about 80% for rain totals up to 0.89 in, and in the 40% range for storms up to 2.41 in. The mass load reductions were statistically significant for all three metals ($p<0.05$) though not for TSS. The reductions were also significant (paired t-test, $p<0.05$) for concentrations of copper and zinc.

The discharge out of the Biofiltration LID site met stormwater action levels to meet TMDL requirements 100% of the time, a 20% improvement in the discharges from the reference site. However, the LID treated only ~2% of the drainage area and likely did not alter the overall end of pipe results sufficiently to meet Stormwater Action Limits (SALs) 100% of the time.

The original estimates for LID technology effectiveness were based on WinSLAMM modeling though final construction and actual drainages varied slightly from those used in the estimates. The Paver LID site was estimated to reduce runoff volumes by ~60% and particle loading by 87%. The observed result of 100% reduction indicates that the model underestimated the effectiveness by as much as 40%, a result that might have been related to the estimated native soil infiltration rate. Estimates of the Biofiltration LID technology effectiveness in reducing runoff volume was 56% versus a measured 57%. The estimate for metal and TSS mass loading ranged between 11% and 18% of the observations, with some metal loads over predicted and some under predicted. The results suggest that the modeling and design work can be used with reasonable confidence in sizing and implementing future biofiltration LID technologies.

The demonstration project successfully evaluated the implementation of LID technology to mitigate stormwater metal contaminants in a naval base commercial area. The outcomes are promising for future implementation at other comparable Navy sites around the country.

ACRONYMS

BMP	Best Management Practice
CO	Commanding Officer
EMC	Event Mean Concentration
FEAD	Facilities Engineer and Acquisition Division
IDIQ	Indefinite Delivery/Indefinite Quantity
IGE	Independent Government Estimate
LID	Low Impact Development
LID Center	Low Impact Development Center, Inc.
MDL	Method Detection Limit
MS4	Municipal Separate Storm Sewer System
NAL	Numeric Action Limits
NAVFACNW	Naval Facilities Command Northwest
NAVFACSW	Naval Facilities Command Southwest
NEX	Navy Exchange
NBSD	Naval Base San Diego
NESDI	Navy Environmental Sustainability Development to Integration
NPDES	National Pollutant Discharge Elimination System
PWO	Public Works Officer
RSD	Relative Standard Deviation
SAL	Stormwater Action Limits
SDRWQCB	San Diego Regional Water Quality Control Board
SIOH	Supervision, Inspection and Overhead
SSC	Space and Naval Warfare Systems Center
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
WER	Water Effects Ratio
WinSLAMM	Windows Source Loading and Management Model

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1. INTRODUCTION

This report describes an evaluation of the effectiveness of using low impact development (LID) to mitigate stormwater runoff and metal contaminants from Navy commercial areas. The project was conducted at Naval Base San Diego (NBSD) between 2014 and 2017. The project included a site assessment and technical design down-selection process, construction of two LID demonstration sites, and a monitoring effort to assess the effectiveness of the two sites to reduce runoff of stormwater metal contaminants. The report describes the background, technical approach, methods employed, results, and lessons learned. The work was performed under Project 497 of the Navy's Environmental Sustainability Development to Integration (NESDI) program (http://greenfleet.dodlive.mil/environment/nesdi/).

1.1 BACKGROUND

Navy facility stormwater is regulated under Clean Water Act of 1972 National Pollutant Discharge Elimination System (NPDES) permits. The Navy's industrial stormwater permits commonly have benchmarks or numeric concentration limits for metals such as copper and zinc that are designed to ensure that water quality standards are met within the waterbodies that receive the discharge. The requirements can become even more stringent to meet Total Maximum Daily Load (TMDL) limitations when the discharges are to waterbodies that are identified as impaired for these metals (Clean Water Act, 1972). These limits have become more stringent over the last 10 years as a result of an increasing concern over the ability to meet the relatively low receiving water toxic thresholds posed by these metals. More recently, the State of California has added a requirement that stormwater also meet an acute toxicity requirement (San Diego Regional Water Quality Control Board, 2013) that commonly fails as a result of elevated copper and zinc concentrations (Katz, Rosen, & Arias, 2006).

Navy facilities have difficulty meeting compliance with the stricter limits on copper, zinc, and toxicity because they have condensed industrial operations, contain site materials that can be a source of metals, have a high percentage of impervious surface, considerable vehicular traffic, and have very short conveyance distances to reach receiving waters. These particular site conditions can and do lead to relatively high stormwater copper and zinc levels relative to benchmarks or limits and commonly fail acute toxicity testing.

Best management practices (BMP) have been identified and employed around the country to mitigate stormwater metal contaminants. These control measures range from simple housekeeping efforts such as moving activities that generate contaminants indoors up to highly sophisticated and expensive stormwater capture and treatment systems that remove the contaminants once they are entrained in the stormwater.

LID technology is a comprehensive decentralized approach to stormwater management. The underlying premise to the technology is to attempt to mimic a site's predevelopment hydrology by using design techniques that detain, infiltrate, filter, or store runoff close to its source. The United States Environmental Protection Agency defines LID as "a *sustainable landscaping approach that can be used to replicate or restore natural watershed functions and/or address targeted watershed goals and objectives"* (https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/termsandacronyms/search.do). Building LID into development projects provides a potential cost savings to stormwater management by reducing the amount overall runoff and thus the costs associated with the construction and maintenance of large conveyance infrastructure and/or end-of-pipe treatment facilities.

The Energy Independence and Security Act of 2007 requires LID to be applied to federal facilities. As a result, the Navy developed policy that directed LID to be considered in the "design for all projects that have a stormwater management element" (Memorandum for Deputy Chief of Naval Operations Fleet Readiness and Logistics Deputy Commandant of the Marine Corps Installations and Logistics, November 2007). The stated goal of the policy was "no net increase in stormwater runoff volume and sediment of nutrient loading from major renovation and construction projects."

LID technology is being implemented across the nation at Navy and Marine Corps facilities. However, for the most part, their implementation has not been fully tested for their ability to reduce runoff or contaminants, particularly metals. The lack of effectiveness data on LID technology resulted in the Naval Facilities Command Southwest (NAVFACSW) and Northwest (NAVFACNW) Environmental to jointly submit a need to the NESDI program to evaluate LID for Storm Water Run-off Control in February 2012 (NESDI Need ID 167). The need outlined the Navy's challenges with "finding feasible and cost effective methods for controlling stormwater runoff that exceeds NPDES permit limits and benchmarks from operational areas, and from non-industrial areas of Navy bases." The need identified the benefits that could be derived from knowing what the expectations, effectiveness, cost, and technical limitations of a LID feature are before choosing to implement it at a site.

In response to the NESDI Need, the Environmental Sciences Branch of Space and Naval Warfare SPAWAR Systems Center Pacific (SSC Pacific) submitted a pre-proposal (NESDI ID 167) for demonstrating the effectiveness of LID to mitigate stormwater runoff and metal contaminants from Navy commercial areas in November 2012. The full proposal was submitted in November 2013 (NESDI ID 113) and the project was approved in April 2014. The NESDI demonstration project (NESDI ID 497) was conducted between June 2014 and December 2017, with completion of this final report.

2. DEMONSTRATION GOALS

The main goal of this NESDI demonstration project was to validate the effectiveness of LID in reducing stormwater flow and metal concentrations from Navy commercial areas. Navy commercial areas are a common land use at many military bases across the nation. They are comparable to big-box style commercial spaces that contain relatively large retail buildings with a high percentage of impervious surfaces dedicated to parking and streets. The relatively large areas of impervious surfaces used for parking generally results in a relatively high ratio of runoff volume to rainfall. The relatively high amount of vehicle traffic combined with building materials, primarily roofing, asphalt, and concrete can and do generate both aqueous and particle-borne stormwater metals. Thus, these sites offer potential opportunities to implement LID technologies that can be designed to intercept large areas of stormwater flows and contaminants without significantly impacting the available space. Demonstrating LID at these locations provides broad applicability across the Navy.

3. TECHNICAL APPROACH

The demonstration technical approach was to retrofit two LID technologies in the commercial land use portion of NBSD (Figure 1) and compare the volume and contaminant concentrations in stormwater runoff discharging from the LID technologies to the volume and concentrations discharging from non-LID portions of the drainage. This side-by-side comparison versus influent/effluent evaluation was primarily chosen for logistical reasons. The demonstration outcomes were also evaluated against regulatory limits specific the site and to predicted effectiveness. The demonstration approach had five major components:

1) Engagement with base personnel and approval
2) Site Selection
3) Technology Selection
4) Buildout
5) Monitoring

3.1 ENGAGEMENT WITH BASE PERSONNEL AND APPROVAL:

Engagement with base personnel began prior to the initiation of the NESDI project. SSC Pacific staff has a long-running involvement with Navy stormwater issues in the San Diego metro area generally and with NBSD in particular. SSC Pacific routinely engaged with base environmental staff on a variety of stormwater issues and was aware that NBSD had particular conditions that made it an excellent demonstration location. In particular, the base has a relatively large commercial area that is regulated as a Municipal Separate Storm Sewer System (MS4) area under the base's individual NPDES permit and was therefore subject to stormwater monitoring. The historic monitoring data for stormwater runoff at this site showed relatively high metal concentrations (Katz & Arias, 2014). Additionally, the site discharges to the Chollas Creek, a waterbody that is impaired for copper, lead, and zinc and is regulated under a TMDL. The combination of these conditions suggested that the base would provide not only an excellent demonstration location for testing LID for mitigating stormwater metals but would also be an opportunity to provide some regulatory relief.

Given the opportunity to implement LID, SSC Pacific personnel were directed to the Public Works Officer (PWO) to start the approval process to build out the LID technologies. The PWO agreed with the environmental need and with the general concept of building out LID technologies on the base, but within some general constraints for final approval by the base Commanding Officer (CO) including: not tying LID to any of the buildings on the site, no net loss of parking spaces, and to provide a short list of proposed demonstration sites. Base environmental staff was consulted on a regular basis as SSC Pacific staff along with contractors evaluated specific site locations, selected technologies, and supported the final selections brought to the CO for approval. The final decision was made by the CO with the only caveat that construction not occur around the Christmas holidays.

3.2 LID SITE SELECTION

A full evaluation of the NBSD commercial area was conducted by SSC Pacific staff together with staff from the Low Impact Development Center, Inc. (LID Center) of Beltsville, MD and their subcontractor Geosyntec Consultants. The team effort included a review of GIS maps, utility maps, aerial photos, construction documents, geotechnical reports, and as-built documents for the Navy Exchange (NEX) and Commissary buildings and associated infrastructure as well as a site visit to locate and assess stormwater drainage structures for location, size, and elevations. The team focused on determining drainage areas and the extent of the storm drain system and locations of existing

underground utilities for potential conflicts with construction. The team selected potential sites based on a combination of quantitative factors such as physical features, drainage characteristics, and costs and qualitative factors that were based on the experience of the project team. The full report of this effort is included in the Appendices.

3.3 TECHNOLOGY SELECTION

The next step in the approach was to evaluate various LID technologies that were applicable to the site conditions and to mitigating metals. The team, in concert with Dr. Bob Pitt of the University of Alabama, evaluated the drainage characteristics and potential performance for a range of LID technologies using the Windows Source Loading and Management Model (WinSLAMM). The model had been recently modified and calibrated for use at Navy facilities under a separate NESDI project (NESDI Project 45; Katz et al., 2014; Pitt, 2014). The effort was focused on the use of bioretention and media-based technologies because they are considered proven reliable technology, are accepted in the regulatory community, and are the most effective at treating metals or can be modified to effectively treat metals. The model evaluated the expected performance at each of the potential sites based on sizing criteria derived from the City of San Diego’s Stormwater Design Manual (San Diego County, 2016). The final technology selection was based on the site down-selection process, the outcomes of the performance modeling, and on meeting a list of key criteria related to bioretention media-based BMPs and compliance with Navy facilities LID criteria (Naval Facilities Engineering Command, 2010). The technology down selection combined with the site selection was briefed to the CO, PWO, and environmental staff for final approval (step 1). Two sites with two technologies were approved for demonstration. The full report of this effort is included in the Appendices.

3.4 BUILDOUT

Once the approval was given to conduct the demonstration, the next step in the approach was to build out the two LID technologies. SSC Pacific and base environmental staff were directed to meet with the NBSD Facilities Engineer and Acquisition Division (FEAD) to contract, plan, and oversee the buildout of the technologies. This process required that the basic design elements be included in the statement of work generated for the two LID technologies so that the contract could be put out to bid. The staff at the LID Center put these plans together with an estimate of expected costs of the buildout. Construction was awarded to a contractor under an indefinite delivery/indefinite quantity (IDIQ) contract already in-place with NBSD. Construction on the two LID technologies was conducted over a four month period. Additional oversight of the build out of specific LID elements was conducted by the LID Center subcontractor Geosyntec.

3.5 MONITORING

SSC Pacific staff conducted all field monitoring including the installation of stormwater sampling equipment to monitor rainfall and flow and to collect flow-weighted composite stormwater samples. The work followed a monitoring plan generated by the LID Center. Water was collected from the outflow of the two LID technologies and from two additional locations that acted as reference areas with comparable surface and runoff characteristics. The technical approach was to evaluate stormwater runoff loading (concentrations and flow) from the LID technologies and compare them to the runoff from the reference non-LID areas. Storms were monitored for rainfall; flow; total and dissolved copper, lead, and zinc; pH; total hardness; total alkalinity; and total suspended solids (TSS). Water samples were collected on a flow-weighted basis, thus providing chemical results as event-mean concentrations (EMC).

The monitoring data were evaluated for the reduction in total and dissolved metals, TSS, flow, and loading (concentration x flow) by comparing the levels discharging from the LID technology to the levels discharging from a reference area. The data were also evaluated specifically against Stormwater Action Limits (SAL) that are the threshold metal concentrations allowed under the Chollas Creek TMDL to provide the environmental staff with results that directly support the base's environmental program. Finally, the monitoring outcomes were also compared to the effectiveness predicted in the technology selection process to assess the technology selection process when implementing the LID technology at other locations.

4. METHODS

4.1 PROJECT CHRONOLGY

The NESDI project (NESDI ID 497) had its origin in a Need submitted by NAVFACSW and NAVFACNW in February 2012 (NESDI Need ID 167). In response, SSC Pacific scientists submitted a pre-proposal (NESDI ID 167) in November 2012. The project moved forward for full proposal (NESDI ID 113) in November 2013 and approved for funding in April 2014. The project management plan was finalized in June 2014. Work began with a contract award to the LID Center for support of the LID design and technology selection process in June 2014; by engaging with NBSD environmental staff and the LID Center to set the approval process in motion in November 2014.

The project concepts were briefed to the NBSD PWO in December of 2014 with an approval to move forward but included some constraints on implementation related to mitigating the loss of parking and not connecting the LID to buildings. The LID site and technology selection process was finalized in May 2015 and was briefed again to the PWO in June 2015. The briefing resulted in a final adjustment from constructing two separate types and locations of biofiltration cells to one biofiltration cell and one permeable paver site to ensure no loss of parking spaces. The final technology selection was briefed to the CO in July 2015 and was approved for demonstration with the single caveat that construction would not disrupt the Christmas holiday season starting in November.

The FEAD was immediately contacted after the CO's approval to begin the site approval and construction contracting process to build out the LID demonstration sites. Site approvals were finalized in September 2015 and a contract request for bid went out in October, which was accepted in late December. During this time the LID Center generated a monitoring plan in a report dated October 2015. The time constraints put in place by the CO resulted in construction starting in late February 2016. The two LID technology installations were completed in late May 2016.

Stormwater monitoring equipment was installed at both LID sites and at two reference sites in October 2016. Eleven rain events were monitored between November 2016 and February 2017. Five of the eleven events were monitored for chemistry. LID performance reporting by the LID Center was conducted between March and April 2017.

4.2 DEMONSTRATION SITE

As described previously, the commercial area of NBSD was chosen as a demonstration site. This 62-acre area of the base contains the Naval Exchange, commissary, food court, commercial bank, gas station, and a car wash as well as a Navy Lodge and a number of office buildings along the northern edge of the property (Figure 1). The area is composed of two drainage areas with similar structural stormwater conveyance systems made up of a series of inlet drains and pipes that eventually transport stormwater through two ~2.5-ft diameter outlet pipes at the southeastern edge of the property into Chollas Creek (Figure 2). There is also a small area of non-Navy commercial properties north of the base that potentially discharge through the Navy's stormwater conveyance system. This area roughly consists of 56% impervious parking and an additional 23% of roofing surface area, half of which discharges onto the impervious pavement. Thus, nearly 80% of rain that falls onto this area is transported across impervious surfaces prior to entering in to the storm drain conveyance system.

This portion of the base is regulated as a Municipal Separate Storm Sewer System (MS4) area under the base's individual NPDES permit. It is further regulated under a TMDL because it

discharges to the adjacent Chollas Creek, which is listed as an impaired water body for copper, lead, and zinc. Stormwater from the two outfalls in this drainage area was monitored between 2012 and 2014 (Katz & Arias, 2014). Stormwater concentrations of total copper, lead, and zinc ranged from 82 to 198, 4.5 to 17.3, and 148 to 496 µg/L, respectively. The levels of copper and zinc commonly exceeded the SAL daily maximum threshold values limits under the TMDL of 54, 23, and 420 µg/L, respectively. Other drainages were evaluated for runoff potential for copper and zinc under the NESDI WinSLAMM Project 455 (Katz et al., 2014). The results for both drainage areas indicated that paved parking areas were the primary land uses in generating copper and zinc.

4.2.1 LID Site Selection

The selection process for identifying potential locations within the demonstration site amenable to LID implementation was primarily performed by the LID Center with site visits performed by SSC Pacific and Geosyntec personnel. The full process was documented in a report that is included in Appendix A. The process included an evaluation of quantitative factors based on physical features such as soils, slope, depth of the water table, underground utilities, and storm drain infrastructure. It also included constraints imposed by the base CO and PWO that roofs/buildings not be used because it would require multiple Command approvals, that there would be no loss in parking spaces, and that the build out be aesthetically pleasing. Additionally, the project team considered the following factors in the selection process:

- The site is representative of land use (e.g., traffic volume, roof type, etc.).
- The surfaces (e.g., parking spaces, roofs, etc.) are in good condition.
- There are no excessive unstabilized sediment loads or future construction activities that may drain to the site.
- There are no potential storage areas, loading areas, or fueling areas that can have excessive metals loading that drain to the site.
- The surface drainage area can be clearly defined.
- The storm drain outfall for the area can be clearly defined.
- The condition of the storm drain pipes is known.
- There is opportunity to install monitoring equipment in an existing storm drain structure and it is accessible in a safe manner.
- There are no underground utilities that require special protection or relocation.
- A reference monitoring site with similar drainage characteristics and land use that can be monitored is in close proximity.
- Monitoring equipment (e.g., shelters or flowmeters) can be accessible at the surface and placed in steel security boxes that do not hinder site activities. Available electrical power at the monitoring location is a bonus, but not mandatory.
- The subsurface soil conditions are known and suitable for the proposed stormwater control.
- The groundwater table is well below the bottom of the stormwater control BMP (and drainage system) with minimal potential for groundwater mounding interfering with the infiltrating water from the stormwater control or underdrains.
- Groundwater contamination potential is also minimal.

Using the above guidance the team evaluated the available maps, aerial photos, construction and geotechnical reports, and data from site visits to derive a list of 27 sub-drainages for locating

potential LID technologies (Figure 3). The sub-drainages were then specifically evaluated for 13 criteria to identify the most favorable location options shown in

Figure 1. Commercial area of NBSD used for the LID demonstration project. The area is composed of two main stormwater drainage areas (outlined in white and beige) both discharging to Chollas Creek at the southeast corner of the property. The area outlined in red is composed of non-Navy commercial properties potentially discharging on to the base. Aerial photo supplied by Google Earth.

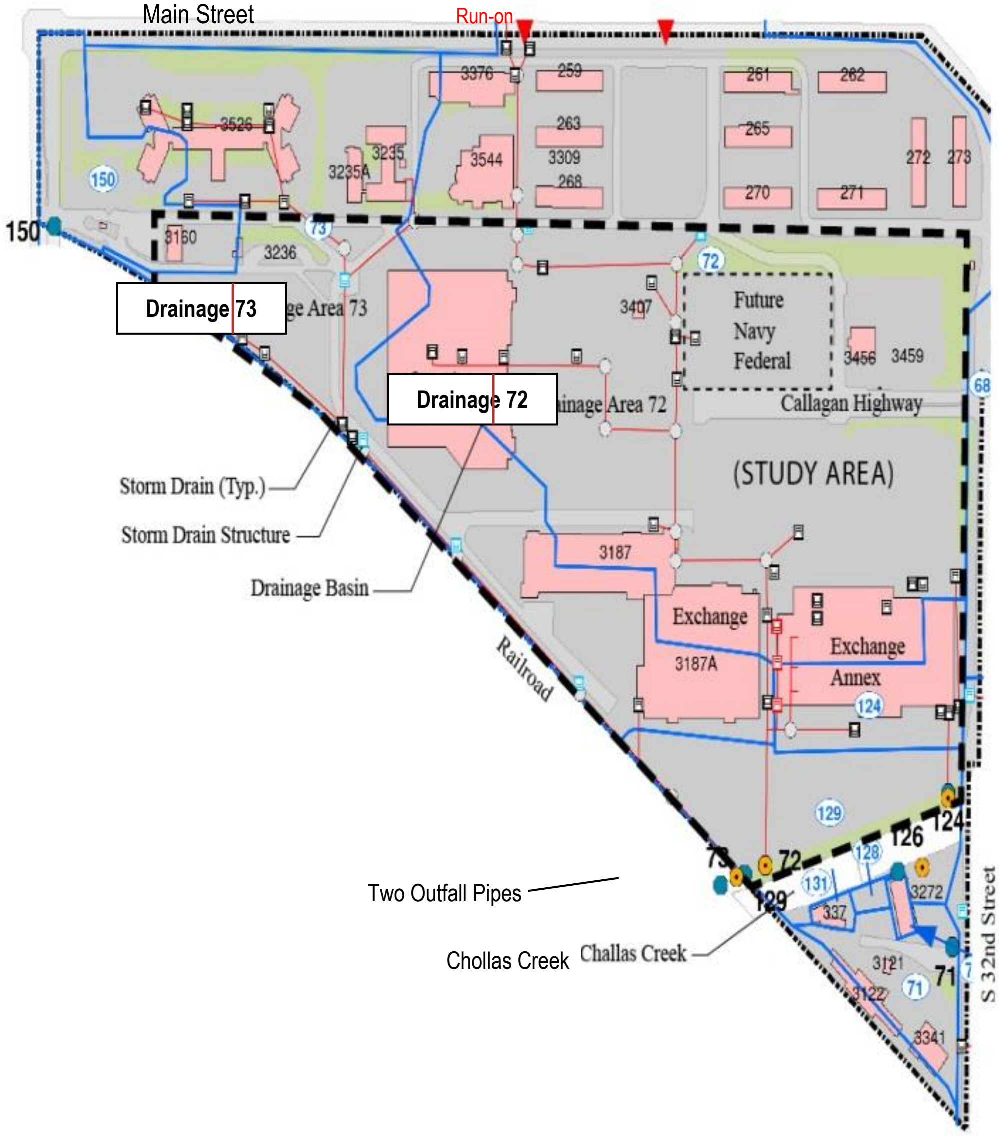

Figure 2. Stormwater conveyance system for NBSD commercial area drainages 72 (west) and 73 (east). Potential run-on from non-Navy commercial area is shown at the top.

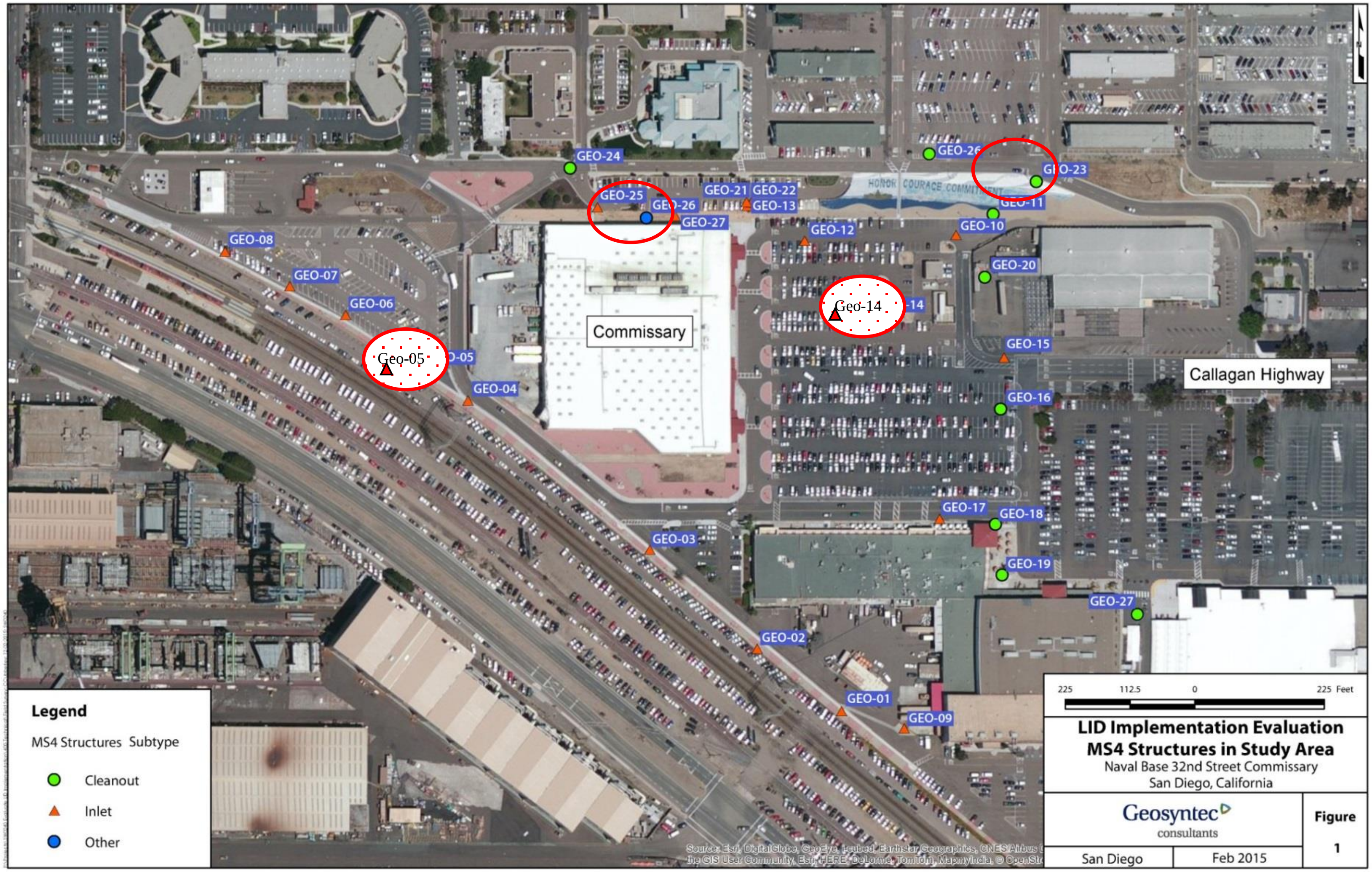

Figure 3. Potential locations identified for LID technology implementation. The four red-circled locations were downselected using criteria shown in Table 1. The two filled in circles identify the final sub-drainages chosen for demonstration. Aerial photo supplied by Google Earth.

Table 1. Sub-drainage location down-selection process based on 13 criteria. Grayed out cells represent four sub-drainages that best met the criteria.

	Sub Drainage Location Number																										
Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	●	○	○	○	●	●	○	○	○	○	○	○	○	●	○	○	●	○	○	○	○	○	●	●	○	●	○
2	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	○	●	●	●	●	●	●	●	●	○
3	●	●	●	●	●	●	●	●	●	○	○	●	○	●	○	○	○	○	●	●	●	●	●	○	○	●	○
4	○	○	●	○	●	●	●	●	○	○	●	●	○	●	●	●	●	○	○	○	●	●	●	○	●	●	○
5	○	○	●	○	○	●	○	○	●	○	●	○	○	●	○	○	●	○	○	●	○	○	○	○	○	○	●
6	●	●	●	●	●	●	●	●	●	○	●	○	○	●	●	●	●	○	○	●	●	●	●	●	●	●	○
7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
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9	●	●	●	●	●	●	●	●	●	●	○	○	○	●	○	○	○	○	○	●	○	○	●	○	○	●	○
10	●	●	●	●	●	●	●	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	●	○	○	●	○
11	●	●	●	●	●	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	●	○	○	●	○
12	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○
13	○	○	○	○	●	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	●	○	○	●	○

Criteria:

1. Representative of land use
2. Surfaces in good condition
3. No excessive sediment loads
4. No hot spots
5. Defined drainage areas
6. Known outfall
7. Existing storm drain condition known
8. Opportunity for monitoring
9. No utility conflicts
10. Comparison to reference monitoring
11. Monitoring equipment accessibility
12. Favorable soils conditions
13. Constructability

4.2.2 Technology Selection

The technology selection process primarily evaluated bioretention media-based systems that use filtration, sorption, or ion exchange because they are considered the most effective and efficient way to mitigate and reduce the pollutant load and impacts from metals (Clark & Pitt, 2012). Stormwater entering into a biofiltration cell infiltrates through the soil/media until it fills up the interstitial volume when it then enters into a perforated drain and allowed to overflow into the conveyance system. The mitigation benefit is potentially a result of particle removal, chemical absorption by the soil/media, and volume reduction captured in the cell and or infiltration to groundwater. Other treatment technologies such as street sweeping, green roofs, swales, and various proprietary devices were evaluated but were excluded because of space considerations, appropriateness, operations considerations, and limited effectiveness for treatment of metals. Further, bioretention technology is proven and accepted by the regulatory community. The criteria used in the selection of bioretention media-based technologies at each of the four sub-drainages identified previously in the site selection process are shown in Table 2. Conceptual drawings and schematics were developed for each site. An additional step was to utilize WinSLAMM to estimate the potential effectiveness of LID technologies in reducing the annual loads of copper, lead, and zinc given design criteria specific to each of the locations (Appendix B).

The model evaluated designs that were sized based on generally accepted rules recommended in the San Diego County Stormwater Design Manual (San Diego County, 2016) of a bioretention cell of approximately 2,200 ft^2 per acre of runoff. The model evaluated two different bioretention volumes at each site based on differing cell depth options of 2.5 and 5 ft. Underdrains were included because infiltration capacity of the underlying native soils estimated from regional soils reports indicated poorly drained soils. Some of the candidate sub-drainage sites had a much larger ratio of drainage area to LID size than is recommended in the San Diego County Stormwater Design Manual because of space and operational constraints. As a result two sizes of underdrains were evaluated to ensure adequate time to dewater the system before the next flow event. Bioretention cells were designed to include 1 to 2 ft of media as that is where the most effective treatment activity occurs though additional depth of media, gravel, or pipes can provide supplemental detention storage for holding runoff until it infiltrates or evaporates.

Removal efficiencies were evaluated using WinSLAMM for the overall drainages (Pitt, 2014). The results were normalized in terms of the percentage ratio of the LID treatment cell area to paved drainage area. The evaluation was conducted for all four sub-drainage sites and included estimates of the amount of volume that is reduced through infiltration, evaporation, and evapotranspiration; the amount of solids that are filtered by the media; and the overall reduction of concentration in the effluent for copper, zinc, and lead. A generic compost biofiltration media was used in the evaluation given the likelihood that untested or expensive materials would not be used in the final construction. The expected residence time of stormwater in contact with the biofilter media was estimated to be between 5 and 10 hours for these sites, which maximizes the capture of the filtered forms of the metals in the media.

Model results for the sub-drainage 5 biofiltration site behind the Commissary are shown in

Table 3. The size of the LID technology was initially designed to roughly 0.034 acres (1500 ft^2) with an estimated drainage of 0.8 acres. The effectiveness of the cell indicated a long-term average effluent concentration of copper, lead, and zinc of ~66, 8, and 400 µg/L with efficiencies of 54%, 74%, and 53%, respectively. Costs of construction were initially estimated at ~$40 thousand with low maintenance requirements consisting of semi-annual removal of sediment and debris from the cell and inlet and trimming and replacing dead plant materials.

A similar analysis was completed for all four sub-drainage locations and reported out by the LID Center in their final report in May 2015. When briefing the site and technology selections to the PWO in June 2015, it was decided that the four parking spaces lost to construction of the biofiltration cell in sub-drainage 14 in front of the Commissary could be recovered if permeable paver LID technology was applied at the location instead. Similar to biofiltration, permeable pavers allow stormwater runoff to infiltrate through the pavers to a subsurface chamber below grade, thereby reducing the overall volume runoff. The request resulted in a relatively quick effort to update the modeling and plans to include a LID permeable paver technology for demonstration. The initial estimates for loading reduction in the sub-drainage 14 site with pavers was ~50% for copper and zinc, and 80% for lead. These two technologies were briefed to and approved by the CO on 7 July 2015. The two demonstration sites from this point forward are referred to as the Biofiltration (sub-drainage 5) and Pavers (sub-drainage 14) sites. Pre-construction pictures of the two sites are shown in Figure 4.

On a final note, during the site and technology down-selection process consideration was given to evaluating a LID bioretention technology that was under construction as part of the Navy Federal Credit Union bank located nearby to the Paver site (Figure 1). Ultimately, the decision was made to not do this because the timing for completing the construction was not known and the exact materials used in the biofiltration could not be determined. The construction at the site was finally completed in late 2015, but too late to be considered as an alternative to building out the two LID technologies demonstrated under this project.

Table 2. LID technology selection criteria. Sub-drainage sites 5 and 14 (gray cells) were chosen for demonstration of the biofiltration and permeable paver technologies, respectively.

Criteria		Sub-Drainage 5	Sub-Drainage 14	Sub-Drainage 23	Sub-Drainage 26
1	Can function with improper maintenance	○	○	○	○
2	Can perform without plants established	●	●	●	●
3	Can be properly configured	○	○	○	○
4	Appropriate drainage area	○	●	○	○
5	Sufficient monitoring information	●	●	●	●
6	Vendor availability	●	●	●	●
7	Adaptability to local conditions	●	●	●	●
8	Can be analyzed with WINSLAMM	●	●	●	●
9	BMP is resilient	○	○	○	○
10	Non-proprietary or proprietary	●	●	●	●
11	Predictable maintenance	●	●	●	●
12	Can be designed with local criteria	●	●	●	●
13	No long-term life-cycle issues	●	●	●	●
14	Can be decommissioned	●	●	●	●
15	No excessive training	●	●	●	●

Key: ● Meets criteria, ○ Partially meets criteria

Table 3. WinSLAMM model estimates for metals reduction in bioretention cell for sub-drainage 5. The initial estimate for the permeable pavers for sub-drainage 14 was ~50% for copper and zinc, and 80% for lead.

Site	Estimate
Project Site	1
Biofilter Footprint (ft^2)	1,500
Drainage Area (ac)	1.15
Biofilter Size (% of area)	2.99
% of Runoff Reduction	19.1
Ratio of Runoff to Rain Volume (Rv)	0.56
% Particulate Solids Mass Reduction	77.7
Particulate Solids Effluent Concentration (mg/L)	21
Total Cu Effluent Concentration (ug/L)	65.9
% Total Cu Mass Reduction	**54.3**
Total Pb Effluent Concentration (ug/L)	8.0
% Total Pb Mass Reduction	**73.7**
Total Zn Effluent Concentration (ug/L)	404
% Total Zn Mass Reduction	**52.6**
Median Particle Size (um)	2.26
Maximum Stage (ft)	4.58
Maximum Surface Ponding (hrs)	6.1
Total Inflow (ft^3)	1,771,000
Volume Infiltration (ft^3)	381,432
Underdrain Discharge (ft^3)	1,367,870
Evapotranspiration (ET) Water Losses (ft^3)	38,644
Surface Discharge (ft^3)	9,471
Surface Ponding Events(>72 hrs)	0
Runoff Producing Events (out of 2,348 total events and %)	1,068 (46%)

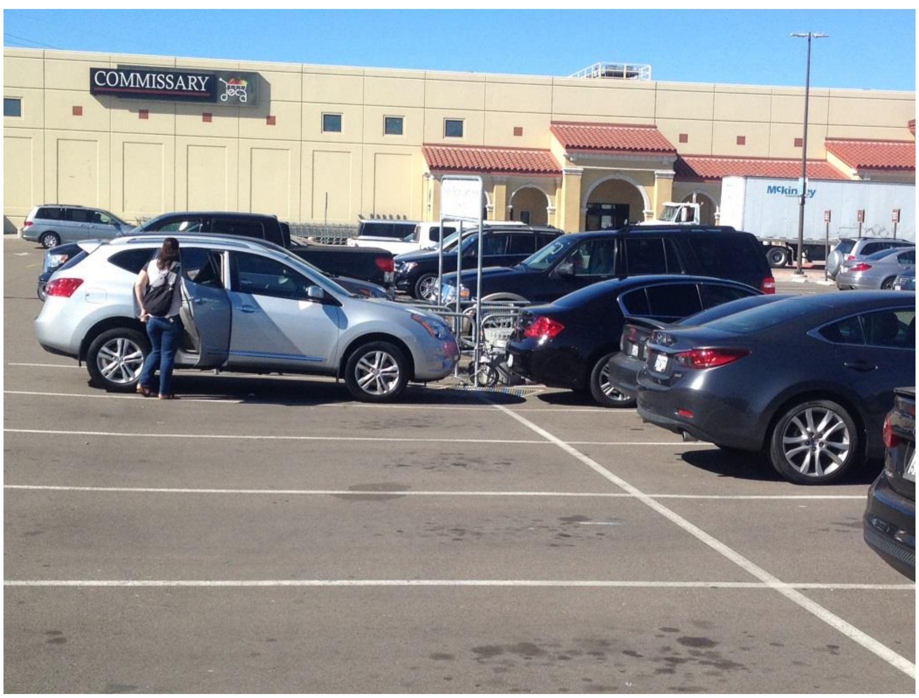


Figure 4. Photos of the pre-construction locations of the biofiltration site in sub-drainage 5 (top) and Paver site in sub-drainage 14 (bottom).

4.3 BUILD OUT

The NBSD FEAD facilitated the build out of the two LID technologies starting with the site approval process, contracting, and construction oversight. The effort started immediately after approval by the CO on 7 July. The LID Center generated the LID design package that included the site, drainage, and landscape plans along with and material recommendations (Figure 5 through Figure 9). A site visit was conducted with NBSD environmental and FEAD staff, SSC Pacific personnel, and personnel from the proposed construction company already contracted under a NBSD IDIQ contract to identify the areas for construction and to discuss the LID specifications. The design package along with a statement of work and independent government estimate (IGE) was forwarded to the FEAD for the contracting process. An additional design review was conducted by Geosyntec to provide recommendations for the aggregate materials planned beneath the permeable pavers and the bioretention cell, and address the need for liner systems (Appendix C). The initial bid cost came in on 14 October 2015 for $75 thousand (~46%) higher than originally estimated in the IGE (Table 4). Negotiations ensued with the contractor to reassess design elements that might have been overestimated or misunderstood. The final cost of the construction was $189.6 thousand or $28 thousand (17%) higher than originally estimated. The overall cost of building out the projects with the 8% supervision, inspection and overhead (SIOH) fees was $205 thousand. The contract was finalized on 17 December 2015 roughly 5 months after the process began.

4.3.1 Paver LID Site

Construction of the Paver LID site in front of the Commissary began on 22 February 2016 and was completed on 15 March 2016. The final constructed size was 2800 ft^2 overall with an estimated drainage area of 0.89 acres based on a recent topographic. Construction required the rebuilding of the central drainage vault and reconnection of the main storm drain pipes. Monitoring and clean out pipes were also installed. Personnel from Geosyntec monitored the construction site on a regular basis as part of their sub-contract with the LID Center. Their efforts were invaluable for successful implementation of the LID as they identified and corrected issues with stone sizes and depths of the paver underlayment as well as the perforation sizes used in the underdrain pipe. It cannot be overemphasized how important it was to have knowledgeable oversight on construction. Photos of various stages of construction are shown in Figure 10.

It rained 0.29 in on 7 March 2016, just before the Paver site was completed. Three days later a 2–3-ft diameter sink-hole developed on the Paver site. This was the first of eventually three sink holes that formed on the site shortly after rain events. The cause of the sink hole was finally determined in mid-May 2016 when it was discovered that there was a previously unknown, but open sewer line located just a few inches below the bottom grade of the site. This line was finally sealed off by the contractor. The additional work resulted in an additional cost of $5,600 that had to be paid out of the NESDI project because the problem was considered an “unforeseen condition.”

The final constructed Paver LID site is shown in Figure 11 and included the following key elements:

1) ~35 x 80 ft (~2800 ft^2 overall);
2) ~38 in depth below grade;
3) ~3360 ft^3 of storage;
4) ~8 in of #8 stone underlain by 30 in of #57 stone;

5) Schedule 40 6 in perforated pipe (1/4 -in holes);
6) drain cleanouts at both ends of the site;
7) permeable pavers with 3/8 -in spacing;
8) overflow drain at site midpoint;
9) 0.89-acre area drainage area;
10) recent topographic survey provided by NBSD FEAD.

4.3.2 Biofiltration LID Site

Construction of the Biofiltration LID site behind the Commissary began on 14 March 2016 and was completed on 26 May 2016. The final constructed size of the cell was ~1600 ft^2 overall having an estimated drainage of 0.38 acres based on a topographic survey conducted specifically for the project. Construction required the rebuilding of the central drainage vault and realignment and reconnection of the main storm drain pipes. A backflow preventer was installed on the outflow of the underdrain along with a clean out pipe. Personnel from Geosyntec monitored the construction site on a regular basis as part of their sub-contract with the LID Center. Again, their efforts were invaluable for successful implementation of the LID as they identified and corrected issues with the size of the catch basin overflow box, depth of the soil media, the location of the perforated underdrain pipe, and removal of extraneous pipe. As a result the catch basin was enlarged to standard size and the underdrain location was altered and expanded to cover most of the cell area. The extraneous pipe was removed by the contractor. The media depth was shy of recommended depth from the San Diego County Stormwater Design Manual by ~4 in but could not be altered given the elevations of the fixed components in the cell at the time the issue was discovered. It again cannot be overemphasized how important it was to have knowledgeable oversight on construction. Photos of various stages of construction are shown in Figure 13.

The drought tolerant plants chosen for the biofiltration LID cell were originally based on San Diego County Stormwater Design Manual. A couple of the plants in the design were updated based on a NBSD xeriscape design guidance document provided by the FEAD. The final plants selected for installation are shown in Table 5 and Figure 12. Final biofiltration landscape design with plant layout.Figure 12, and provided in Appendix E. The WinSLAMM evaluation indicated that the biofiltration effectiveness would not be significantly impacted by loss of the plants. The final constructed Biofiltration LID site is shown in (Figure 14) and included the following key elements:

1) ~20 x 32 ft (~400 ft^2 overall);
2) ~29-in depth below grade;
3) ~600 ft^3 of storage;
4) 17-in biofiltration soil and mulch media (4 in less than recommended in design manual);
5) ~2 in of #8 stone underlain by ~10 in of #57 stone;
6) Schedule 40 6 -in perforated pipe (1/4-in holes);
7) drain cleanout;
8) backflow preventer on underdrain;
9) blood meal fertilizer by Pro-Pell-it!: soil, Bioswale Mix™, C33- Sand Mix, and Landscape Mulch Blend by AgriService Inc.;
10) plants (see Table 5);

11) 0.38-acre drainage area;

12) topography generated as part of project.

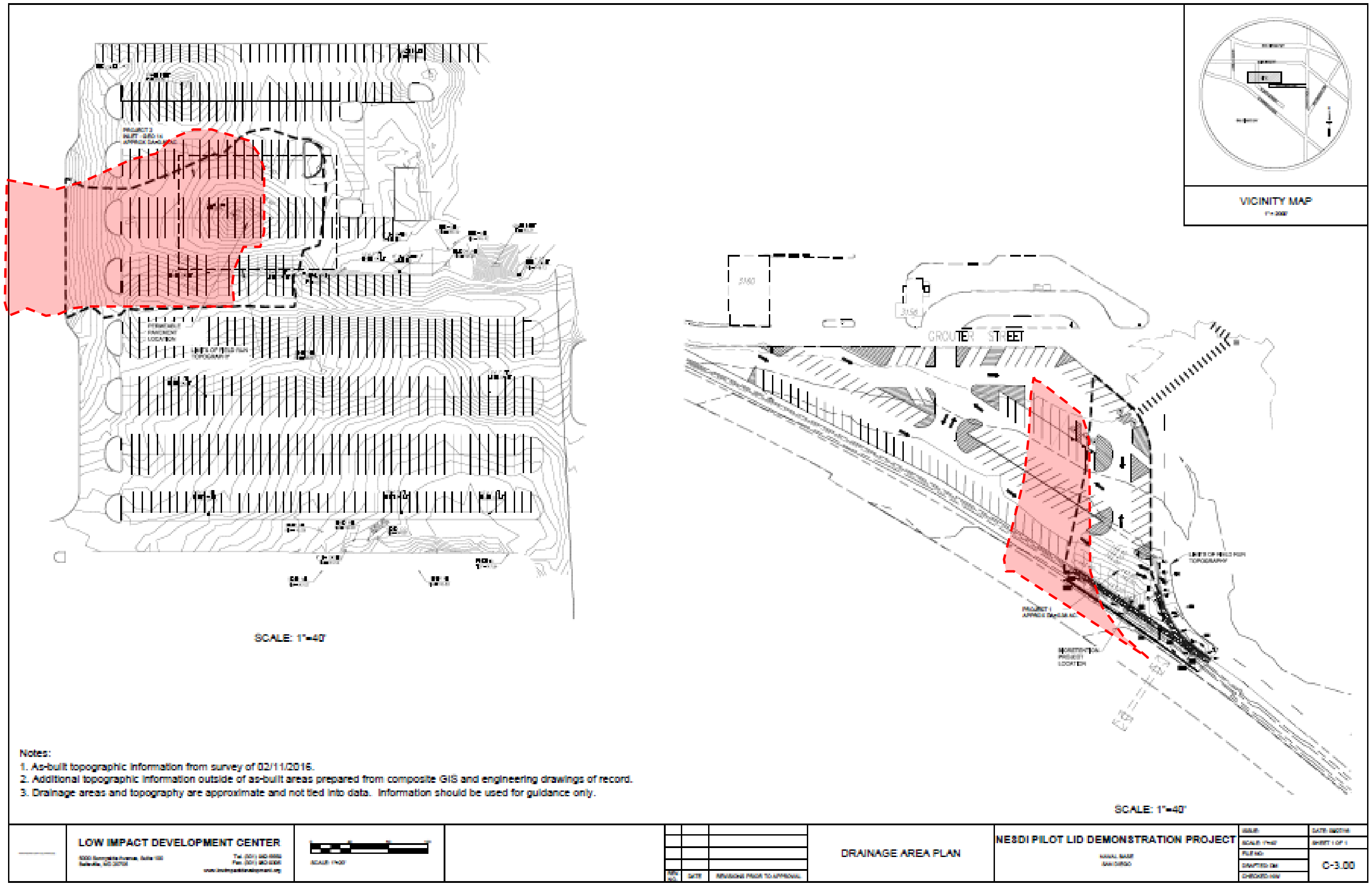
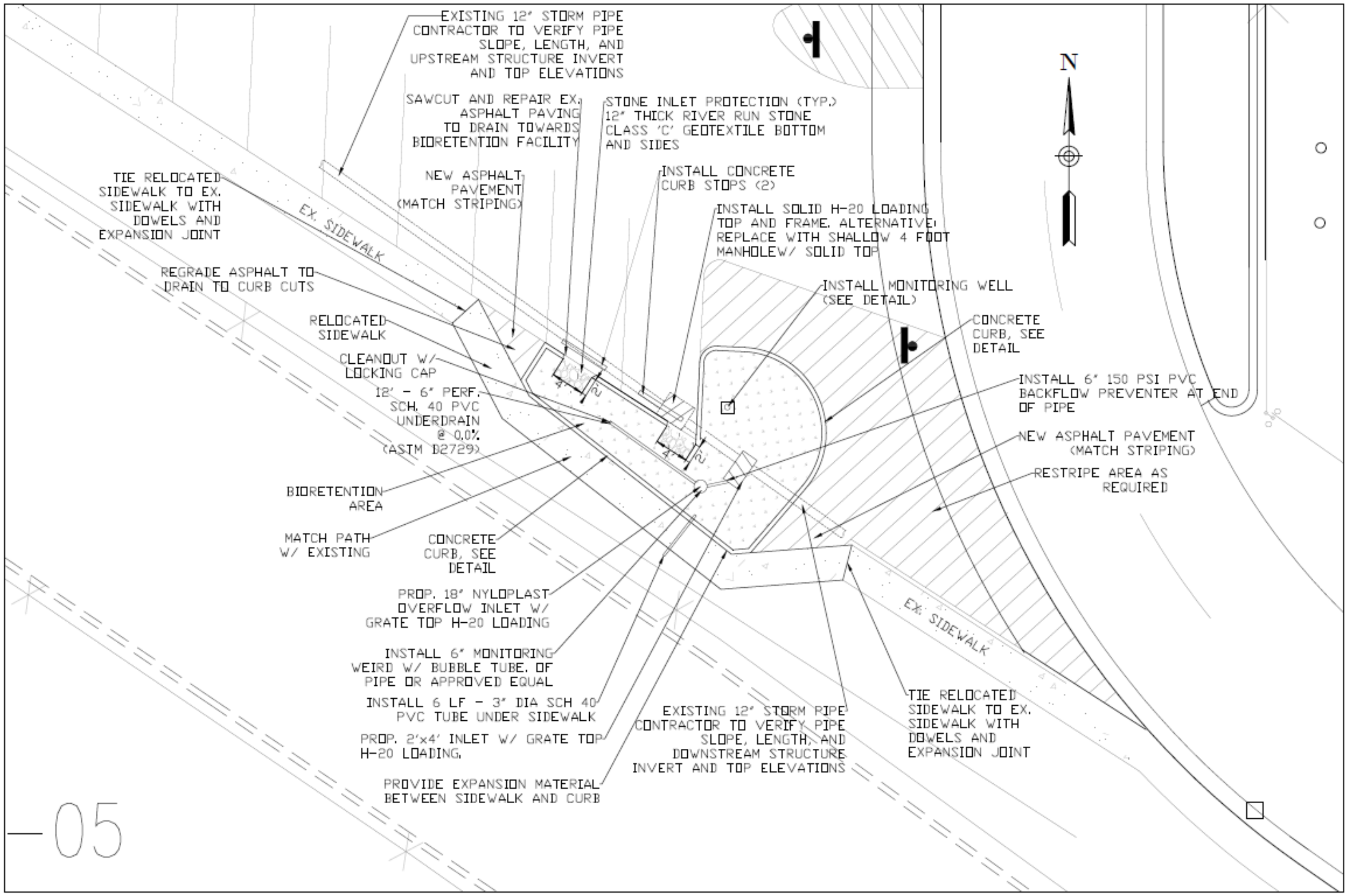


Figure 5. Drainage diagram for NBSD LID demonstration sites. The Paver LID site drainage was estimated at 0.89 acres and the Biofiltration LID site drainage at 0.38 acres.



PROJECT ONE

SCALE: 1"=10

Figure 6. Site plan for Biofiltration site.

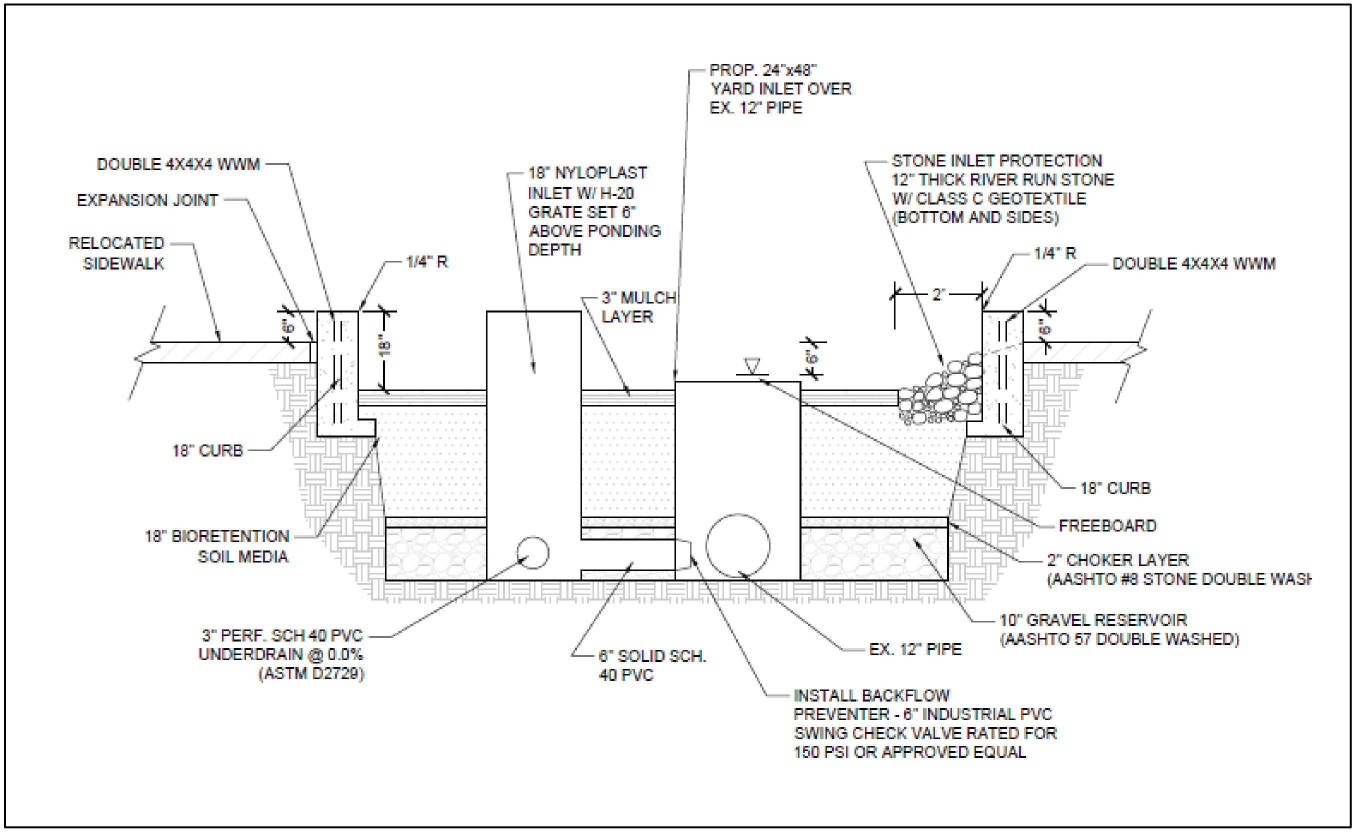
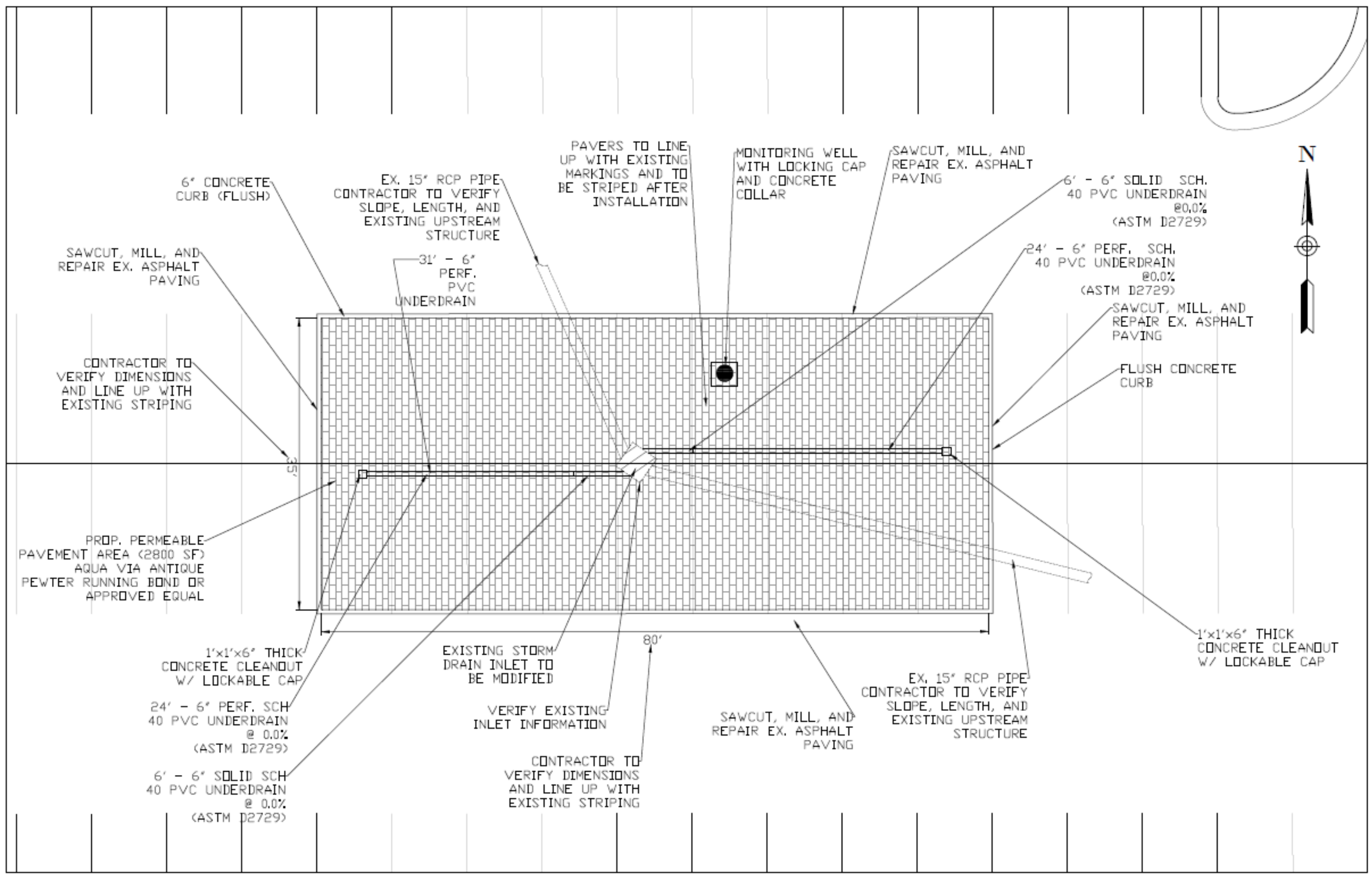


Figure 7. Biofiltration drainage plan.



PROJECT TWO

SCALE: 1"=10

Figure 8. Site plan for Paver LID site.

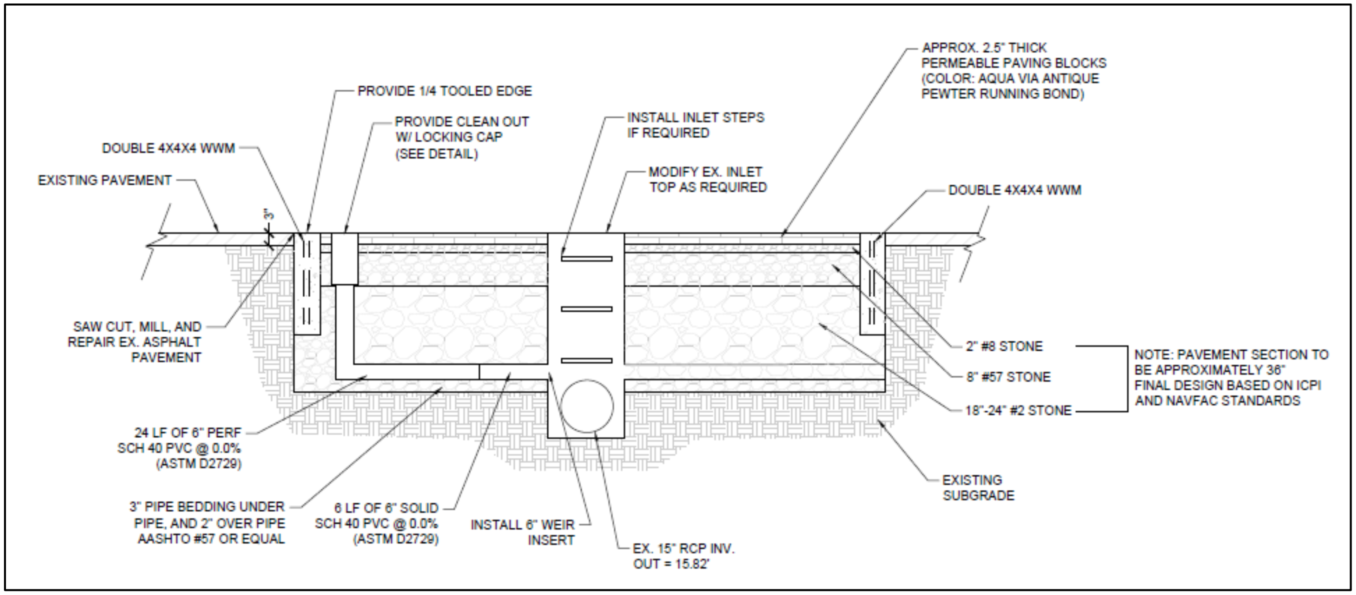


Figure 9. Paver LID site drainage plan.

Table 4. The independent government estimate and initial and final construction bids for building out the Paver and Biofiltration LID technologies including the 8% contracting fees paid to the FEAD.

	IGE ($K)	Initial Bid ($K)	Final Bid ($K)
Paver	119	160	150.1
Biofiltration	43	77	39.5
Contract Cost	162	237	189.6
SIOH Fees	13.0	19.0	15.2
TOTAL	175.0	256.0	204.8

Figure 10. Photos showing various stages of construction of the permeable paver LID technology in front of the Commissary.

Figure 11. View of completed Paver site facing north. The cart return in the upper middle of the photo is roughly in the middle of the site and over the top of the main stormwater conveyance overflow drain.

Table 5. Biofiltration plant selection based on original drought tolerant plant design and modified slightly to match to the NBSD xeriscape design document.

	Quantity	Final Plants	Size/Spacing
PERENNIALS	38	*Iris douglasiana* Pacific Coast Iris	1 gal. @ 12 in o.c.
	15	*Sisyrinchium bellum* Blue-eyed Grass	1 gal. @ 12 in o.c.
GRASSES	65	*Festuca ovina glauca* Blue Fescue	1 gal. @ 12 in o.c.
	8	*Muhlenbergia rigens* Deer Grass	3 gal. @ 36 in o.c.
	50	*Dietes bicolor* Fortnight Lily	1 gal. @ 12 in o.c.

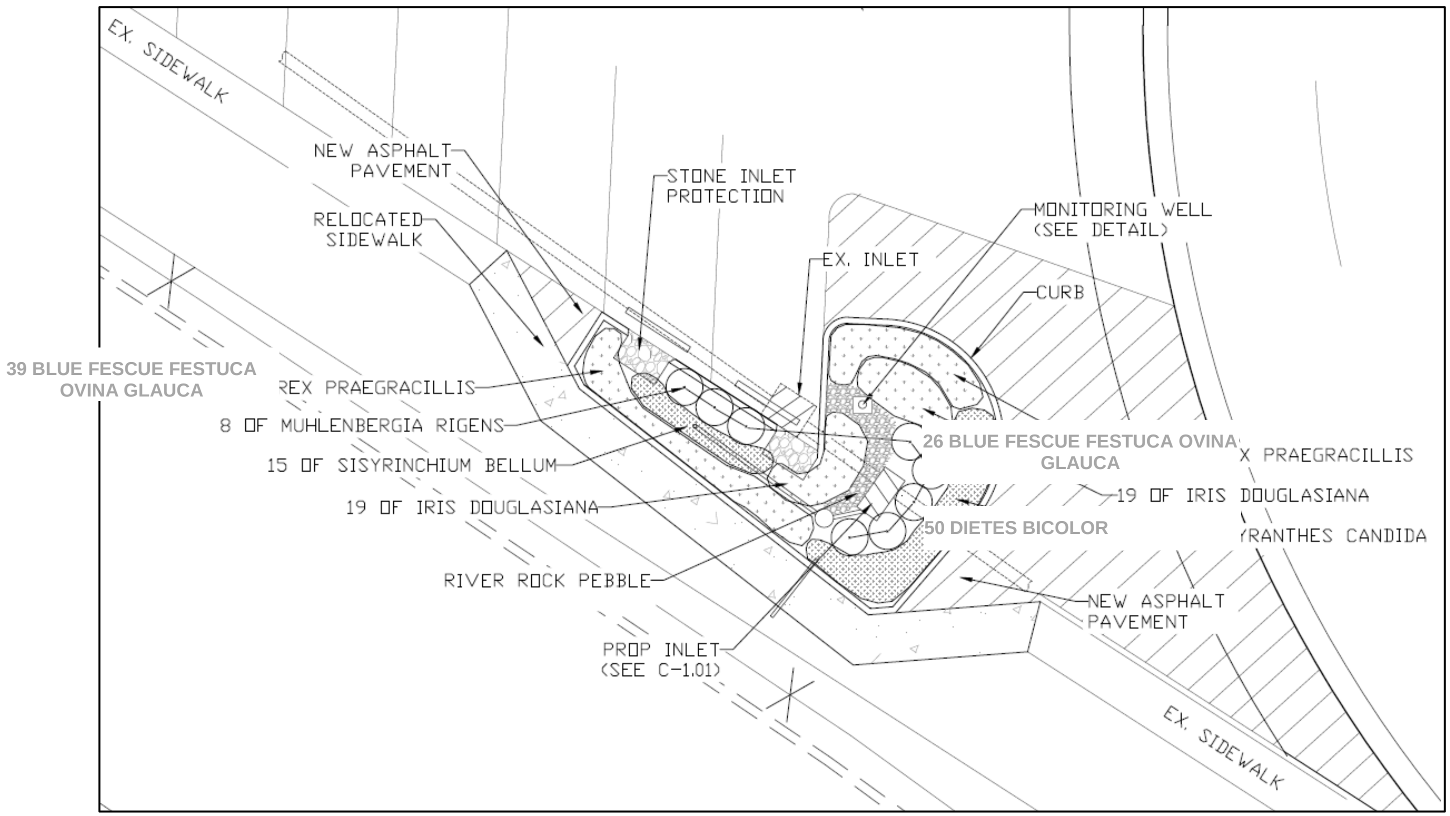


Figure 12. Final biofiltration landscape design with plant layout.

Figure 13. Photos showing various stages of construction of the permeable paver LID technology behind the Commissary.

Figure 14. View of nearly completed Biofiltration site facing west. The fencing and extra stone were removed shortly after the photo was taken.

4.4 MONITORING

4.4.1 Setup

Stormwater monitoring generally followed the guidance provided by the LID Center (Appendix E) and was conducted with a combination of Teledyne/ISCO model 6712 and Hach/America Sigma model 9000 automated portable samplers with attached rain gages, area-velocity flow sensors, and four 1-gal bottle sampling configurations. Two units were set up at each site to measure the outflow pipe of each LID technology and the bypass pipe draining the adjacent upstream reference area. Flow was monitored at the outflow of the LID underdrains. Flow was monitored just downstream of the backflow preventer at the Biofiltration site. A 4-in weir was placed at the end of the outflow pipe at the Paver site to allow the flow sensor to work properly. The samplers measured rainfall in 0.01 in increments with a standard electronic tipping-bucket gage. Flow volume was measured once per minute with a standard Doppler area velocity sensor that measured height of the water in the pipe and flow velocity. The flow volume measurement was used to trigger sample collection throughout the storm event, each time collecting 360-mL aliquots. The volume used to trigger sampling varied by expected rainfall total and the sampling location but was set to collect between 10 and 40 aliquots per storm. The monitoring setup at the Paver site is shown in Figure 15. The monitoring setup at the Biofiltration site is shown in Figure 16.

4.4.2 Water Sample Processing and Analyses

Stormwater collected in multiple 1-gal glass water bottles inside the autosampler were returned to the SSC Pacific laboratory for processing. Stormwater collected within each 1-gal bottle was shaken vigorously and transferred quantitatively into a 5-gal glass carboy. All samples from a site were similarly composited into the glass carboy, shaken vigorously and then distributed to individual pre-preserved bottles for analysis. The samples processed in this manner created a flow-weighted composite sample that represented an event mean concentration (EMC).

Samples were sent to Enviromatrix Analytical, Inc., a local analytical laboratory for analyses of total and dissolved copper, lead, and zinc; TSS; total alkalinity; pH; and total hardness. About half the metal analyses were subcontracted to Weck Laboratories, Inc. Metals were analyzed by Inductively Coupled Plasma-Mass Spectrometry using Environmental Protection Agency (EPA) Method 200.8, TSS by SM2540D, alkalinity by SM2320B, pH by SM4500H+B, and hardness by EPA 200.7. Method detection limits (MDLs) for copper, lead, and zinc ranged between 0.03 and 10 μg/L. All quality assurance/control measures including holding times, blanks, matrix spike recoveries, and duplicates were met throughout the project.

Figure 15. Two Teledyne/ISCO stormwater auto samplers set up inside a shopping cart return corral at Paver site. One sampler was used to measure stormwater out of the paver underdrain while the other was used measure stormwater draining from the adjacent upstream reference area. The rain gage is shown on top of the vault inlet drain.

Figure 16. One Teledyne/ISCO and one Hach/ America Sigma stormwater auto sampler set up inside the biofiltration site. One sampler was used to measure stormwater out of the biofiltration underdrain while the other was used measure stormwater draining from the adjacent upstream reference area. The rain gage is shown on top of the vault inlet drain.

5. RESULTS

5.1.1 Storm Monitoring

The 2016 and 2017 wet season had a total rainfall of ~13 in, which was about 30% above normal and about double the rainfall totals occurring the previous five years. A total of 13 storm events were monitored between 20 November 2016 and 27 February 2017. Of these, five storms were sampled for water chemistry at the Biofiltration site and four at the Paver site. Flow monitoring occurred over rainfall totals ranging between 0.09 and 2.41 in (Table 6).

The upper value of 2.41 in represents a 99th percentile rainfall total for San Diego's International Airport. The water sampling EMC data corresponded to rainfall totals that ranged between 0.17 and 0.85 in, which represent roughly the 23rd and 85th percentile storm events for San Diego, respectively. The EMCs represented between 28% and 95% of the storm totals, a result of pre-planning sample collection to a maximum of a four-bottle composite and because rainfall was commonly intermittent with relatively long breaks in the rainfall.

Table 7 shows the dates and type of storm monitoring data collection. Water sampling typically ranged between 24 and 40 aliquots per storm except for the first storm event when only 1 and 2 sample aliquots were collected in two of the three samplers, a result of the volume trigger having been set too high. These two samples would generally be considered grab samples and not representative of a valid EMC. There was never any flow measured out of the Paver LID site so no stormwater samples were collected or analyzed.

Examples of monitored rainfall, stormflow, and sample collection time data are plotted in Figure 17 through Figure 20. Two common features of the monitored datasets in these drainages is a delay in flow until at least 0.1 in of rain has fallen and that there is a very close relationship between rainfall and runoff, a result of the high level of imperviousness of the drainages. The impact of reduced runoff through the Biofiltration LID site compared to the reference site can be seen in Figure 20, though the plot does not take into account the differences in drainage areas, which are evaluated in detail in the LID Effectiveness section.

5.1.2 Stormwater Chemistry

Stormwater sample chemistry data collected during the five storm events are shown in Table 8. As mentioned previously, the data represent EMC values except for the first set of samples when only one or two aliquots were collected. Metal concentrations were quite variable overall and at each of the three monitored sites with relative standard deviation (RSD) values that ranged between 31% and 110%. Copper concentrations were the most variable. Total copper ranged from 20 to 711µg/L and averaged 189 µg/L, total lead ranged from 0.5 to 20 µg/L and averaged 7.0 µg/L, and total zinc ranged from 56 to 473 µg/L and averaged 201 µg/L. The dissolved fractions of the metals were also highly variable with RSD values that ranged from 29 to 94%. Dissolved copper ranged from 10 to 330 µg/L and averaged 81µg/L, total lead ranged from 0.04 to 5 µg/L and averaged 1.8 µg/L, and total zinc ranged from 16 to 205 µg/L and averaged 109 µg/L. The dissolved fractions ranged between 1% for lead and 94% for copper and averaged 46% overall.

Total metal EMCs generally decreased with increased rainfall at all sites though the dissolved fractions did not show as good a relationship. Total suspended solids also showed a similar decreasing trend with rainfall and was reasonably well correlated with total copper and zinc (r^2 = 0.72 and 0.44, respectively.

Alkalinity, hardness, and pH were measured to help with interpretation of the observed metal speciation, though no relationship was observed between any of these parameters and the metals data. Hardness was also used to calculate dissolved metal concentrations to compare with SAL requirements under the permit. Alkalinity ranged from 5 to 35 mg and averaged 18 mg $CaCO_3$/L, hardness ranged from 10 to 87 mg and averaged 34 mg $CaCO_3$/L, and pH ranged from 6.6 to 7.8 and averaged 7.2.

Table 6. Summary of rain events, rainfall totals, and type of monitored data at all locations. Note that no flow was ever observed out of the Paver LID site.

Date	Rainfall (in)	Monitoring
11/20/2016	0.28	Flow and Chemistry
11/26/2016	0.32	Flow and Chemistry
12/15/2016	0.89	Flow and Chemistry
12/23/2016	0.46	Flow
12/30/2016	1.15	Flow
1/5/2017	0.19	Flow
1/9/2017	0.15	Flow
1/12/2017	0.65	Flow
1/19/2017	0.52	Flow and Chemistry
1/20/2017	1.81	Flow
1/22/2017	0.89	Flow
2/17/2017	1.22	Flow
2/26/2017	2.41	Flow and Chemistry

Table 7. Summary of five storm events monitored for rainfall, runoff volume, and stormwater chemistry. Table shows runoff volume used to trigger water sampling, number of 360 mL aliquots, and the effective rainfall amount represented by the EMC samples. No flow was ever measured out of the Paver LID site.

Storm Start Date	Rain Total (in)	Runoff Volume (gal)	Volume Trigger (gal)	Water Sample Aliquots Collected	EMC Rainfall (in)	Runoff Volume Sampled
Biofiltration LID						
11/20/2016	0.28	276	200	1	0.20	72.5%
11/26/2016	0.32	686	15	24	0.17	52.5%
12/15/2016	0.89	2060	45	24	0.47	52.4%
1/19/2017	0.52*	1815	60	24	0.41	79.3%
2/26/2017	2.41	13457	95	40	0.68	28.2%
Biofiltration Reference						
11/20/2016	0.28	3316	1500	2	0.25	90.5%
11/26/2016	0.32	4396	155	24	0.27	84.6%
12/15/2016	0.89	14449	400	24	0.59	66.4%
1/19/2017	0.52*	10844	430	24	0.49	95.2%
2/26/2017	2.41	44046	390	40	0.85	35.4%
Paver Reference						
11/20/2016	0.28	1308	1500	0	NA	0.0%
11/26/2016	0.32	1743	50	24	0.22	68.8%
12/15/2016	0.89	8501	200	24	0.50	56.5%
1/19/2017	0.52*	5430	215	24	0.49	95.0%
2/26/2017	2.41	26267	225	40	0.83	34.3%

* Rainfall and flow were monitored through an additional 2.33 in of rainfall

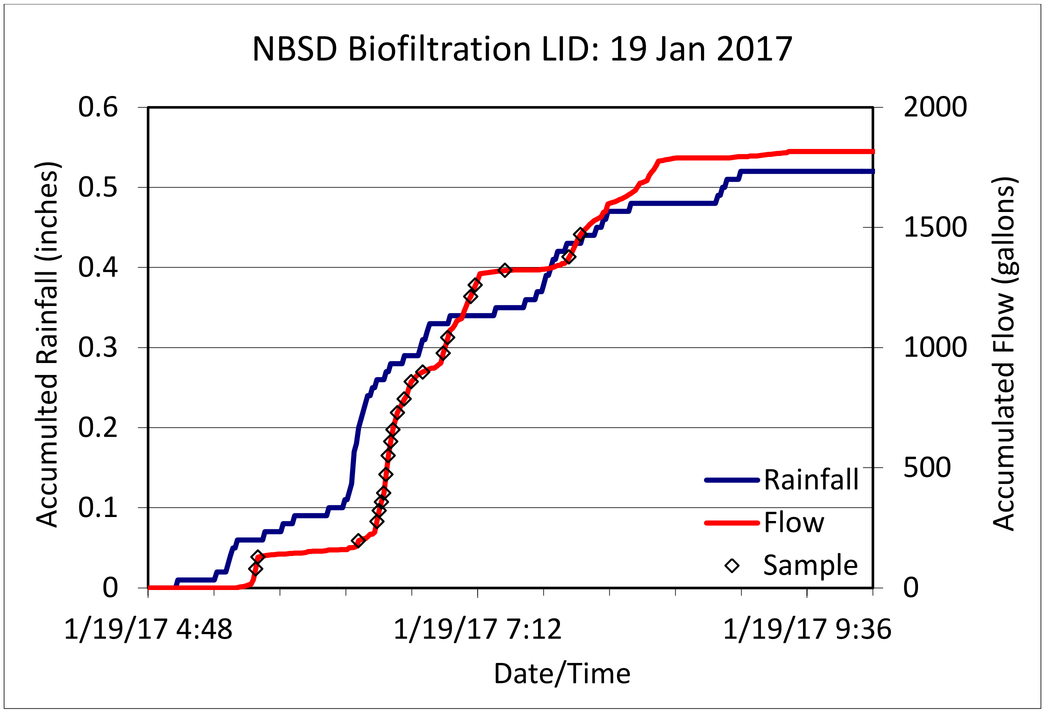


Figure 17. Example of flow monitoring data showing accumulated rainfall, flow volume, and sample collection times for storm event on 19 January 2017 at the Biofiltration LID site.

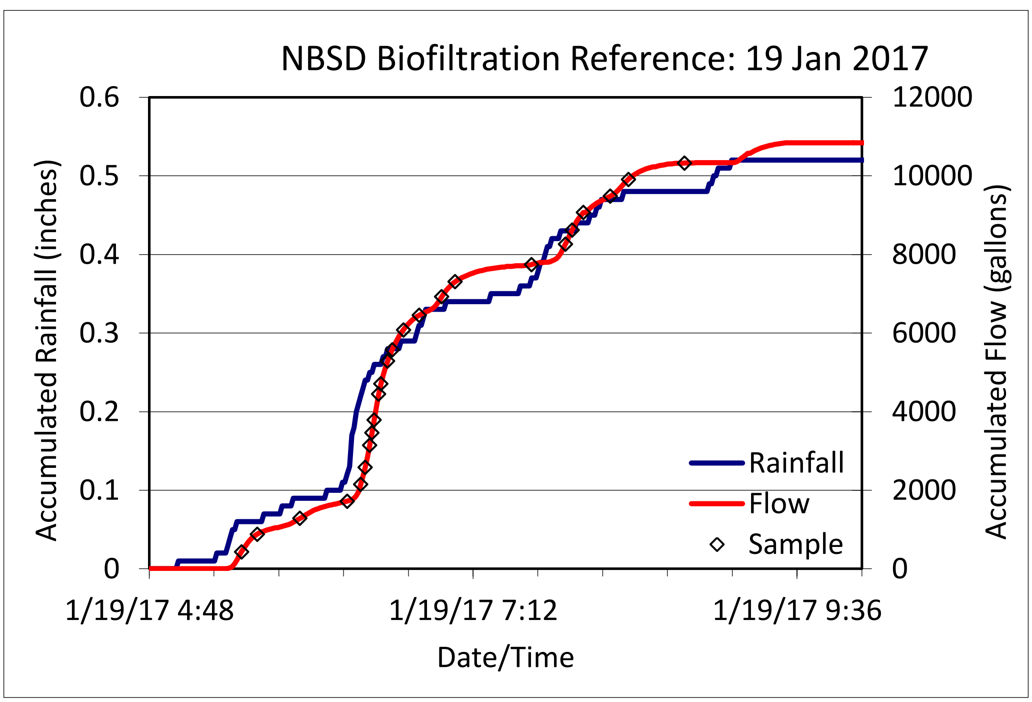


Figure 18. Example of flow monitoring data showing accumulated rainfall, flow volume, and sample collection times for storm event on 19 January 2017 at the Biofiltration reference site.

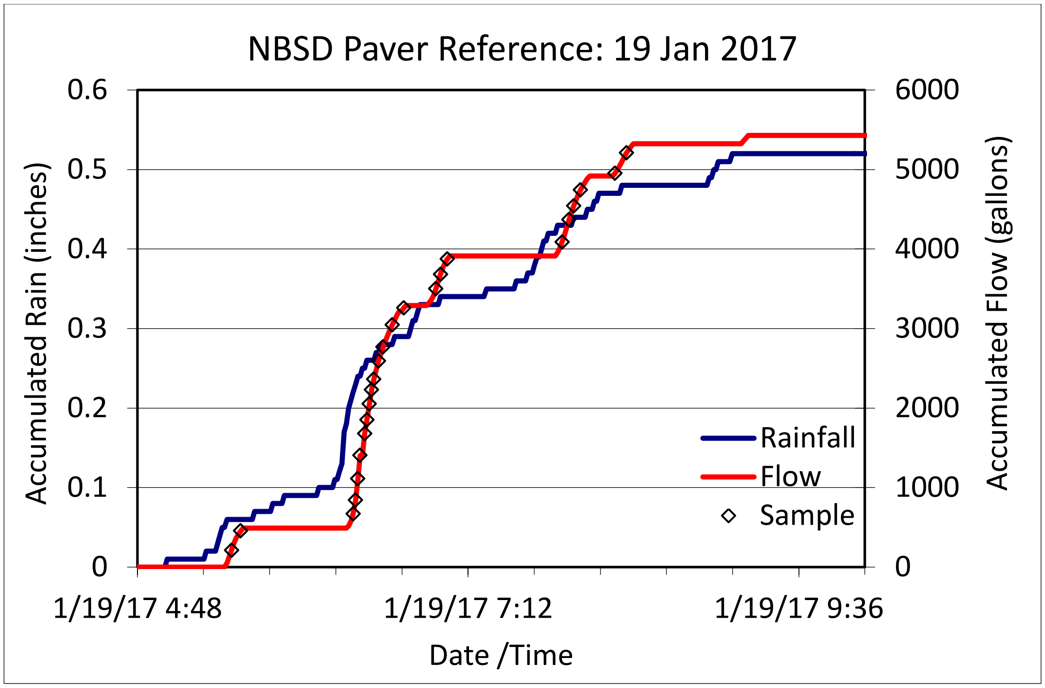


Figure 19. Example of flow monitoring data showing accumulated rainfall, flow volume, and sample collection times for storm event on 19 January 2017 at the Paver reference site. No flow was observed at the Paver LID site.

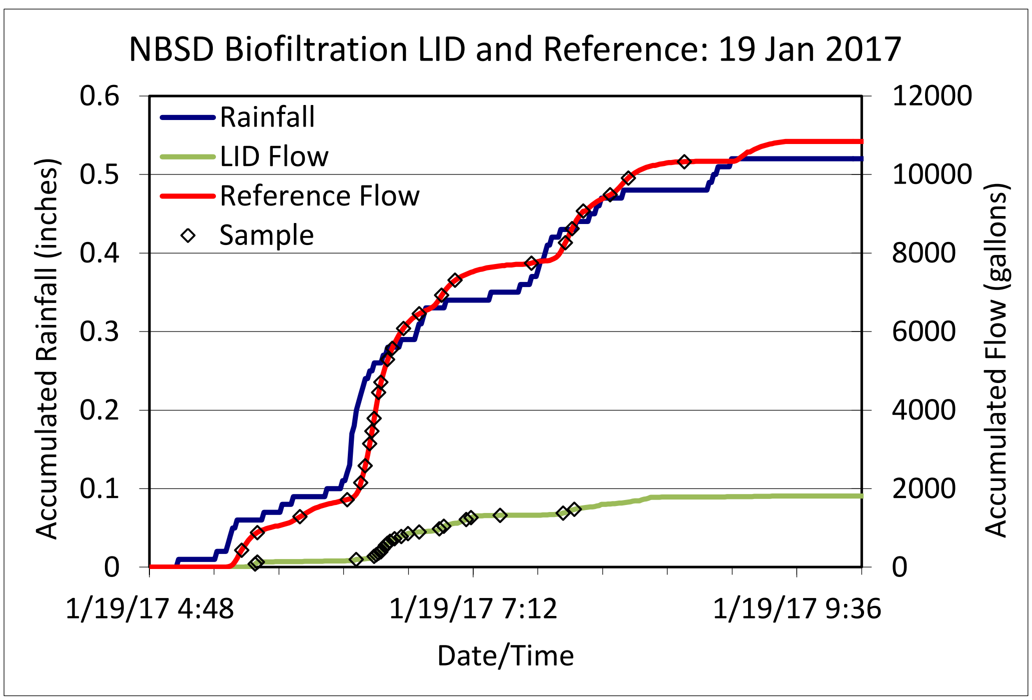


Figure 20. Example of flow monitoring data showing accumulated rainfall, flow volume, and sample collection times for storm event on 19 January 2017 at the Biofiltration LID compared with the Biofiltration reference site. The flows were not normalized to drainage area size.

Table 8. Stormwater chemistry results for five monitored storm events from Biofiltration LID site (Biofilt LID), Biofiltration reference site (Biofilt Ref), and Paver reference site. No samples were collected from the Paver LID site because there was no measured flow out of the system. No samples were collected at the Paver reference (Paver Ref) site during the 20 November storm because the trigger volume had been set too high. Gray cells refer to numbers that are reported at the method detection limit (MDL)

Date	Location	Total Cu (µg/L)	Diss Cu (µg/L)	Total Pb (µg/L)	Diss Pb (µg/L)	Tot Zn (µg/L)	Diss Zn (µg/L)	TSS (mg/L)	Tot Alk (mg/L	Hardness (mg/L)	pH
11/20/2016	Biofilt LID	114	81	10	5	291	164	59	35	87	7.79
	Biofilt Ref	107	94	0.5	5	212	165	40	11	13	7.54
11/26/2016	Biofilt LID	107	78	9	1	279	165	51	33	69	7.13
	Biofilt Ref	194	75	20	1	473	205	76	8	14	6.93
	Paver Ref	711	167	11	1	402	149	98	30	16	7.08
12/15/2016	Biofilt LID	41	35	5.5	2.8	65	56	35	32	35	7.38
	Biofilt Ref	96	73	7.1	3.1	200	180	29	9	10	6.88
	Paver Ref	350	330	4.5	3.3	190	170	53	10	10	6.57
1/19/2017	Biofilt LID	40	22	6.1	0.096	83	27	44	29	45	7.67
	Biofilt Ref	81	18	10	0.095	190	65	62	5	13	6.96
	Paver Ref	550	90	5.9	0.04	190	72	104	9	16	7.12
2/26/2017	Biofilt LID	30	19	4	1	56	16	25	26	50	7.44
	Biofilt Ref	29	10	3	1	80	45	23	5	50	7.14
	Paver Ref	200	39	2	1	101	52	40	6	50	6.97

6. EVALUATION

As described previously, the goal of the LID demonstration was to validate the effectiveness of LID in reducing stormwater flow and metal concentrations from Navy commercial areas. The following discussion describes this evaluation, which was done primarily through a side by side comparison of the stormwater runoff flow volume and concentrations from the two LID technologies and the runoff from the non-LID reference sites. However, an additional evaluation was conducted to compare runoff concentrations from the LID technologies to the SAL thresholds required under the base's Chollas Creek TMDL. The discussion also includes an assessment of the LID technology effectiveness relative to the levels predicted by the technology selection and modeling process to establish their use for future implementation.

6.1 LID EFFECTIVENESS

6.1.1 Paver LID Site

The effectiveness of the Paver LID site is the simpler of the two technology evaluations, given that it was 100% effective in reducing runoff volumes and loading to zero. No measurable flow was observed out of the technology, even during a 2.4-in rainfall, which represents a 99th percentile storm event. The 100% capture of runoff during this large storm that fell over ~48 hours suggests that the LID storage capacity of 3360 ft^3 was augmented with an infiltration rate of 0.37 in/hr (see Figure 21), a value that is a little higher than expected but reasonable for the native silty sands soils found in the area (Appendix C). However, there were anecdotal observations of runoff flowing over the permeable pavers into the catch basin in the center of the site, particularly during intense rainfall conditions. It was not possible to quantify this bypass flow but it is expected that the amount was a relatively small percentage of the total runoff, still suggesting a very effective outcome.

Paver LID Infiltration Rate Calculation

Paver LID area	*= 2800 ft^2*
Paver Storage	*= 3360 ft^3*
Drainage area	*= 0.89 acres = 38,768 ft^2*
Rainfall	*= 2.3" (includes 0.10" pavement loss)/48 hrs*
Runoff Volume	*= 2.31 inches x 38,768 square feet = 7463 ft^3*
Excess volume	*= 7463-3360 = 4103 ft^3*
Infiltration Rate	*= 4103 ft^3 /2800 ft^2 = 1.46 feet/48 hrs = 0.37"/hr*

Figure 21. Calculation box.

6.1.2 Biofiltration LID Site

Runoff volumes, concentrations, and mass loading from the Biofiltration LID technology were evaluated against the non-LID reference site values both on a storm by storm basis and from an evaluation of the overall and average loads. Runoff volumes discharging from the LID site were evaluated after normalizing them to the size of the drainage areas. The Biofiltration LID drainage area was 0.38 acres while the reference drainage area was 0.73 acres.

The amount of drainage area normalized runoff as a function of rainfall for the 13 monitored storms is shown in Figure 22. The relationship shows runoff for both sites were highly correlated to rainfall with r^2 values above 0.93. This result is consistent with previous observations at NBSD given the exceptionally high percentage of impervious surfaces of the drainages. The Biofiltration LID site

reduced runoff volume between 84% and 100% for rainfall less than 0.25 in, by about 70% between 0.25 and 1.15 in, and above 40% up to 2.4 in (Figure 23). The average runoff volume reduction over all storm sizes was 74%.The relatively high reduction in runoff below 0.25 in of rain makes this LID technology very effective in a location like San Diego where that rainfall amount is about the 38th percentile storm size.

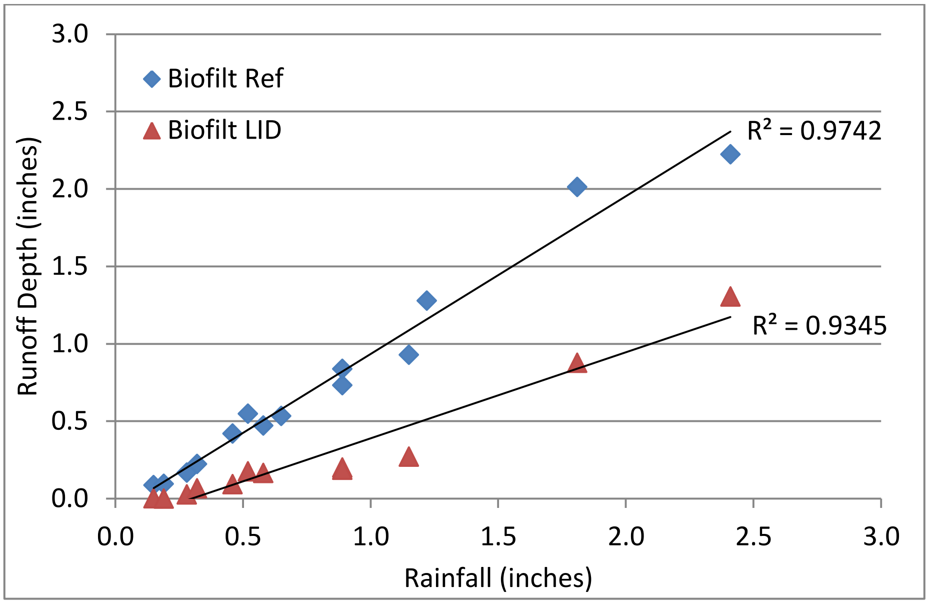


Figure 22. Runoff depth as a function of rainfall for the Biofiltration LID site and Biofiltration reference sites. The data were normalized to drainage area size.

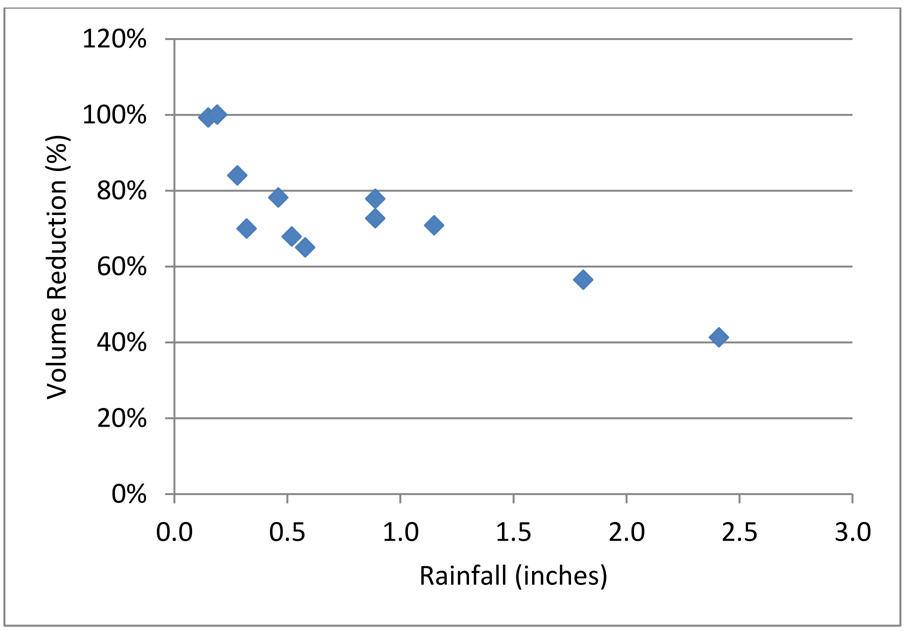


Figure 23. Area normalized volume reduction (%) from the Biofiltration LID site relative to reference as a function of rainfall.

The side by side comparison of the Biofiltration chemistry data (Table 8) showed LID discharge concentrations that were not always reduced below the reference stormwater concentrations as expected. Total copper, lead, and zinc concentrations measured at the two sites for each storm are plotted in Figure 24. The first set of storm results represented a grab sample while the remaining four storms represented EMC data. The first dataset also represented the first storm of the wet season after six months of antecedent dry conditions as well as being the first rainfall after LID installation. In this instance, all three total metal concentrations were higher in the LID runoff than in the reference site runoff. The next three stormwater EMC results were consistent in reducing concentrations of all three metals. The last storm event showed a lower zinc EMC value in the LID runoff but actually 1 μg/L higher for copper and lead, or an increase of 3% and 33%, respectively.

The average reduction in total metal concentrations (paired data) discharging from the LID site, ignoring the first storm of the year grab sample, was 37%, 21%, and 49% for copper, lead, and zinc, respectively, and 36% overall. The paired t-tests indicated that the reduction was significant for total copper and zinc ($p < 0.05$).

A comparable assessment of dissolved metals showed reductions of -16% (an increase), 2%, and 53%, respectively, and 13% overall. The difference in concentrations using paired t-tests was not significant for any of three dissolved metals. The percentage of dissolved metal to total metal concentrations was quite variable for both the Biofiltration LID and reference discharge with no discernable trends with rainfall or concentration. The average fraction of total metals that was dissolved in the runoff was roughly 55% for copper and zinc and 25% for lead.

Particulates as measured by TSS concentration showed a mixed response from the Biofiltration LID implementation. Half the storm events showed higher concentrations of TSS in the LID discharge than reference and half showed a decrease. On average the paired TSS concentrations were lower in runoff from the LID site by ~8%. The variability in the paired data results suggest that the particle loading in the drainages for the LID and reference sites may not have necessarily been as well matched as possible.

A comparison of mass loading from the Biofiltration LID site to the reference site was evaluated for the four storms with EMC data. The mass loading of metals and particles was determined by multiplying the measured EMC of the metal or TSS in the runoff and multiplying by its normalized runoff volume for both the Biofiltration LID and reference sites. The mass loading data are shown in Table 9. The stormwater mass load of copper from the LID site ranged from 0.5 to 2.9 g and averaged 1.2 g compared to 3.2 to 5.3 g and an average of 4.2 g from the reference site. The loading of lead from the LID site ranged from 0.04 to 0.4 g and averaged 0.1 g compared to 0.3 to 0.5 g and an average of 0.4 g from the reference site. The loading of zinc from the LID site ranged from 1.0 to 5.5 g and averaged 2.2 g compared to 7.8 to 13.3 g and an average of 10.0 g from the reference site. The comparable TSS loads were 254 to 2447 g with an average of 951 g versus 1264 to 3834 g with an average of 2309 g.

The Biofiltration LID technology provided an overall average mass load reduction of 68% for metals and particles for rainfall events with rain totals between 0.32 and 2.41 in. The overall reductions were 72%, 63%, 78%, and 59% for copper, lead, zinc, and TSS, respectively. The reductions were statistically significant ($p < 0.05$) for all three metals. For the four storms evaluated between 0.32 in and 0.89 in the discharge volume reduction was 57% indicating that this was the major driver of the effectiveness (57% compared to 68%). But the effectiveness of the mass load reduction by the Biofiltration LID technology was rainfall dependent (Figure 25). Runoff was virtually 100% eliminated below rainfall amounts totaling less than 0.2 in, or for roughly the 28th percentile storm event in San Diego. The mass load reduction of metals and TSS was above 80%

between 0.32 and 0.89 in of rainfall and ranged between 22 and 59% at 2.41 in of rainfall, a 99^{th} percentile storm event.

6.1.3 LID Effectiveness Summary

The two LID technologies were effective at reducing the load of stormwater metal contaminants from the two sites at NBSD. The Paver LID site was 100% effective at eliminating flow from the drainage for all observed storm sizes. It is not known to what extent metals specifically were reduced by implementation at the Paver LID site because there was never any discharge volume to measure. This technology should be effective under almost every rainfall event in San Diego given that it was effective for the 99^{th} percentile storm event. There was some anecdotal observation that some sheet runoff may have bypassed the permeable pavers though it is not known to what extent that might have occurred.

The Biofiltration LID technology was also effective at reducing the mass load of contaminants. The overall reduction of ~68% for the four observed storms was primarily a result of stormwater flow volume reduction (57%). The load reduction was rainfall dependent ranging from 100% effective for rainfall events less than 0.2 in, about 80% for rain totals up to 0.89 in, and in the 40% range for storms up to 2.41 in. The reductions were statistically significant for all three metals ($p < 0.05$) though not for TSS.

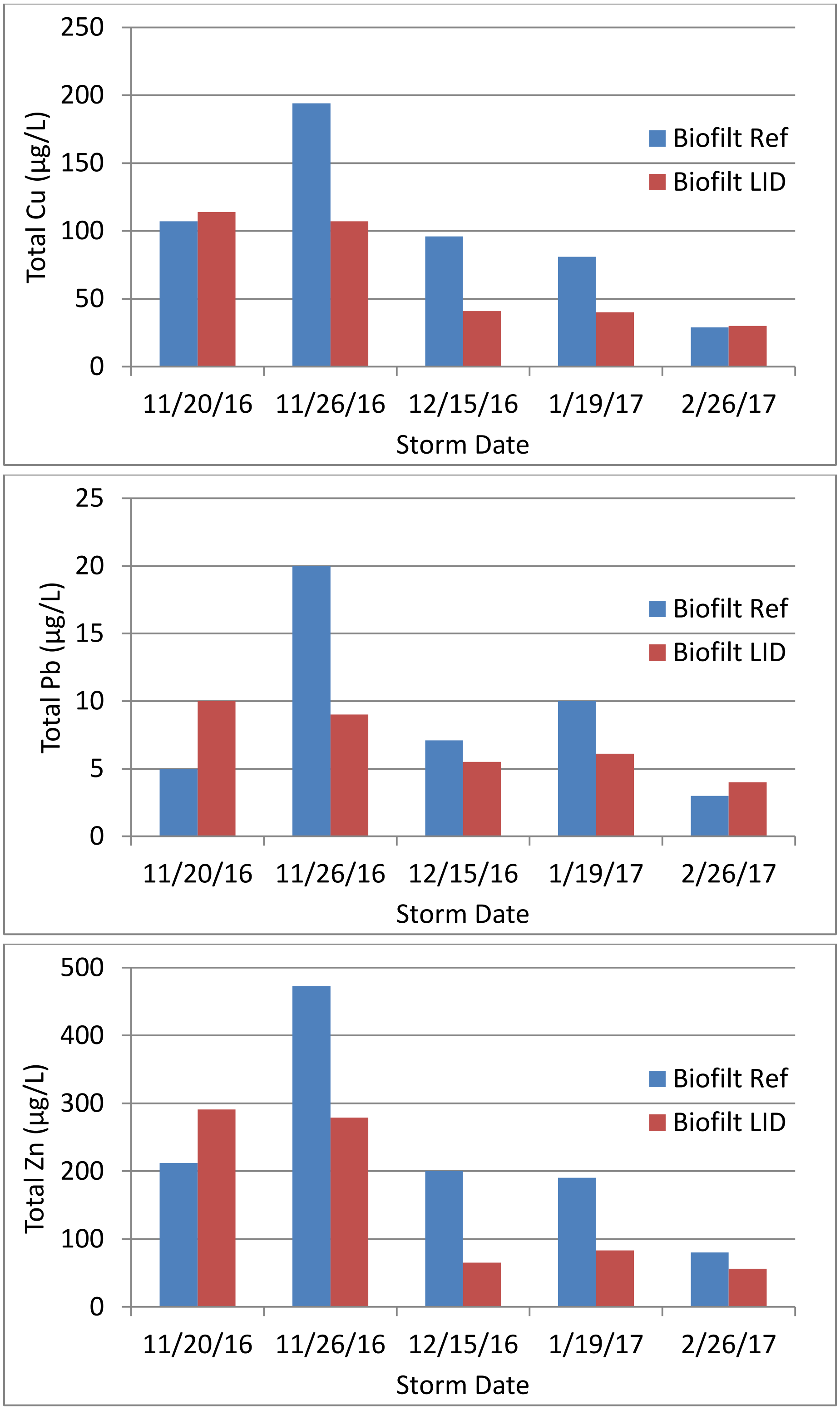


Figure 24. Plots of total copper (top), lead (middle), and zinc (bottom) metal concentrations measured in stormwater from the Biofiltration reference and Biofiltration LID sites for all five monitored storms. Samples collected during the first storm did not represent EMC values.

Table 9. Stormwater runoff volumes, concentrations, and mass loading discharge data for the Biofiltration reference and LID sites. The runoff volumes were normalized to drainage area size. The data from the first storm are based on grab samples, not EMC from composites and were not used in the final evaluation of LID technology effectiveness.

Date	Rainfall (in)	Runoff (L)	Tot Cu (µg/L)	Tot Pb (µg/L)	Tot Zn (µg/L)	TSS (mg/L)	Cu (g)	Pb (g)	Zn (g)	TSS (g)
11/20/2016	0.28	12552	107	0.5	212	40	1.3	0.01	2.7	502
11/26/2016	0.32	16637	194	20	473	76	3.2	0.3	7.9	1264
12/15/2016	0.89	54849	96	7.1	200	29	5.3	0.4	11.0	1591
1/19/2017	0.52	41044	81	10	190	62	3.3	0.4	7.8	2545
2/26/2017	2.41	166715	29	3	80	23	4.8	0.5	13.3	3834
Biofiltration LID										
Date	Rainfall (in)	Runoff (L)	Tot Cu (µg/L)	Tot Pb (µg/L)	Tot Zn (µg/L)	TSS (mg/L)	Cu (g)	Pb (g)	Zn (g)	TSS (g)
11/20/2016	0.28	2009	114	10	291	59	0.2	0.02	0.6	119
11/26/2016	0.32	4988	107	9	279	51	0.5	0.04	1.4	254
12/15/2016	0.89	14979	41	5.5	65	35	0.6	0.1	1.0	524
1/19/2017	0.52	13197	40	6.1	83	44	0.5	0.08	1.1	581
2/26/2017	2.41	97863	30	4	56	25	2.9	0.4	5.5	2447

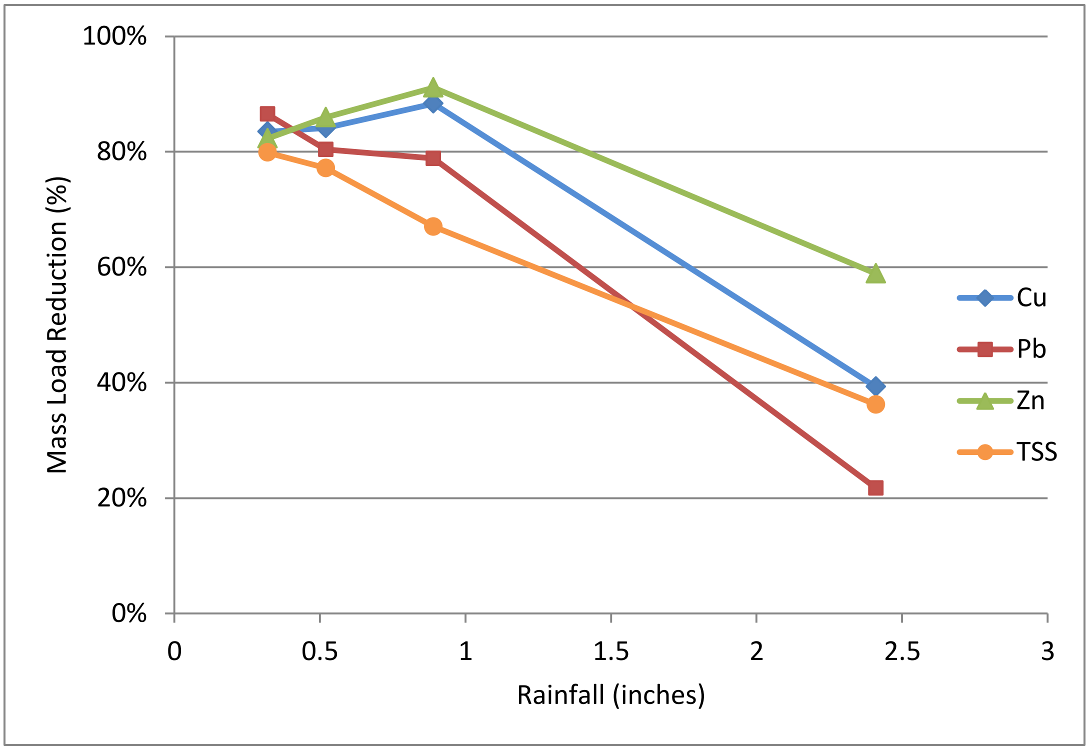


Figure 25. Biofiltration LID technology mass load reduction of metals and TSS relative to reference as a function of rainfall.

6.2 LID IMPACTS ON STORMWATER ACTION LIMITS

Stormwater Action Limits under the NBSD 2013 permit were modified in 2017 to accommodate a SDRWQCB approved water effects ratio (WER) at the levels shown in Table 10. The WER adjustment increased the SAL limits by a factor of 6.998 for copper and 1.711 for zinc (AMEC, 2017). None of the storm events resulted in an exceedance of the SAL daily maximum for water discharging from the Biofiltration LID site (no flow out of the Paver LID site precludes this evaluation). In comparison, the SAL daily maximum for all three metals was exceeded in runoff discharging from the Biofiltration reference site during the 28 November 2016 storm event. While this result showed that the LID discharge met SALs 100% of the time vs. 80% of the time from the reference area (all five storm results are considered acceptable), it does not imply that implementation of this LID technology was sufficient to impact the results measured at the end of pipe in the 16 acre drainage for outfall 73. The results point to a potential for a more significant impact given a larger scale implementation. The Biofiltration LID size of 400 ft^2 was relatively effective at treating a 0.38-acre drainage. A LID technology needed to comparably treat the entire 16-acre drainage would need to be roughly a half-acre in size. A comparable Paver LID treatment in the 46 acre drainage for outfall 72 would require over 3 acres of permeable pavers.

Table 10. Summary of NBSD SAL requirements under the 2013 NBSD permit and updated by the SDRWQCB in 2017 to accommodate WER adjustments for copper, lead, and zinc (AMEC, 2017). The SAL discharge limits were derived to meet the Chollas Creek TMDL.

Total Metal	Monthly Maximum (µg/L)	Daily Maximum (ug/L)
Cu	378	189
Pb	33	16
Zn	718	359

6.3 COMPARISON TO PERFORMANCE ESTIMATES

The original LID technology selection process was focused on using Biofiltration cells at the two sites (LID Center, 2015). Implementation of permeable pavers at the second site was a last minute change requested by the PWO so that no parking spaces would be lost in front of the Commissary. The initial WinSLAMM model performance estimates were based on a biofiltration cell that was roughly 800 ft^2 in size. The post-construction performance estimate of the permeable pavers to reduce runoff was ~60%. The overall reduction of particles was estimated to be ~87%. There were no specific estimates made for metals reduction. The Paver LID site was finally built out at 2800 ft^2 and had 100% reduction in runoff volume and therefore loading of metals and particles. The result suggests that the model underestimated the Paver LID effectiveness by as much as 40%. The higher runoff efficiency might be a result of a higher native soil infiltration rate than expected.

The original performance estimates for the Biofiltration LID site from the technology down-selection process is shown in Table 11. The original size estimate of the drainage area (1.15 acres) was about a factor of three greater than determined by the topography assessment conducted as part of the build-out. The final constructed size of the cell was a factor of nearly four smaller than the estimate. The actual LID size/area was 2% versus an estimated 3%. The runoff volume reduction was estimated at 56% (Rv in table), while estimated reductions in copper, lead, zinc and particle loads were 54%, 74%, 53%, and 78%, respectively. These compare to the observed runoff reduction of 57% and metal mass load reductions of 72%, 63%, 78%, and 59%. The model estimate for runoff was spot on, while it under predicted the copper and zinc loading by ~18% and 15%, over-predicted the lead and TSS reduction by ~11% and 18%. These results, particularly given the slight scaling changes, suggest that the modeling and design work can be used with reasonable confidence in sizing and implementing future biofiltration LID technologies.

Table 11. Original runoff characteristics and effectiveness for Biofiltration LID site copied from the Technology Selection report (Appendix A).

Site	Effectiveness
Project Site	1
Biofilter Footprint (ft^2)	1,500
Drainage Area (ac)	1.15
Biofilter Size (% of area)	2.99
% of Runoff Reduction	19.1
Ratio of Runoff to Rain Volume (Rv)	0.56
% Particulate Solids Mass Reduction	77.7
Particulate Solids Effluent Concentration (mg/L)	21
Total Cu Effluent Concentration (ug/L)	65.9
% Total Cu Mass Reduction	54.3
Total Pb Effluent Concentration (ug/L)	8.0
% Total Pb Mass Reduction	73.7
Total Zn Effluent Concentration (ug/L)	404
% Total Zn Mass Reduction	52.6
Median Particle Size (um)	2.26
Maximum Stage (ft)	4.58
Maximum Surface Ponding (hrs)	6.1
Total Inflow (ft^3)	1,771,000
Volume Infiltration (ft^3)	381,432
Underdrain Discharge (ft^3)	1,367,870
Evapotranspiration (ET) Water Losses (ft^3)	38,644
Surface Discharge (ft^3)	9,471
Surface Ponding Events(>72 hrs)	0
Runoff Producing Events (out of 2,348 total events and %)	1,068 (46%)

7. SUMMARY

Two LID technologies to mitigate stormwater metals were demonstrated in the commercial area of NBSD. The LID technologies included a biofiltration cell draining a 0.38-acre area and permeable pavers with a 0.89-acre drainage area. The demonstration compared the ability of the two technologies to reduce stormwater runoff volume and copper, lead, and zinc concentrations and loading relative to stormwater discharges from non-LID portions of the drainage.

The results of the demonstration showed that the Paver LID technology was 100% effective at reducing runoff and contaminant loading under rainfall conditions ranging up to the 99th percentile storm event. Since there was no discharge out of the Paver LID site it is not known to what extent the technology had in reducing metal concentrations.

The results also showed that the Biofiltration LID technology was also effective at reducing the mass load of contaminants. The overall load reduction was ~68% for storms ranging up to the 99th percentile storm. The results were primarily a result of stormwater flow volume reduction out of the technology that averaged 57%. The load reduction was rainfall dependent ranging from 100% effective for rainfall events less than 0.2 in, about 80% for rain totals up to 0.89 in, and in the 40% range for storms up to 2.41 in. The mass load reductions were statistically significant for all three metals ($p < 0.05$) though not for TSS. The reductions were also significant (paired t-test, $p < 0.05$) for concentrations of copper and zinc.

The discharge out of the Biofiltration LID site met SAL 100% of the time, a 20% improvement in the discharges from the reference site. However, the LID treated only ~2% of the drainage area and likely did not alter the overall end of pipe results sufficiently to meet SALs 100% of the time.

The original estimates for LID technology effectiveness were based on WinSLAMM modeling though final construction and actual drainages varied slightly from those used in the estimates. The Paver LID site was estimated to reduce runoff volumes by ~60% and particle loading by 87%. The observed result of 100% reduction indicates that the model underestimated the effectiveness by as much as 40%, a result that might have been related to the estimated native soil infiltration rate. Estimates of the Biofiltration LID technology effectiveness in reducing runoff volume was 56% versus a measured 57%. The estimate for metal and TSS mass loading ranged between 11% and 18% of the observations, with some metal load over predicted and some under predicted. The results suggest that the modeling and design work can be used with reasonable confidence in sizing and implementing future biofiltration LID technologies.

8. LESSONS LEARNED

This demonstration project successfully evaluated the implementation of LID technology to mitigate stormwater metal contaminants in a naval base commercial area. While the outcomes are promising for future implementation, the project was particularly challenging because it required a sizeable construction retrofit requiring concurrence of the Commanding Officer, Captain Jones, Commander Cho (PWO) and Larry Williams (Deputy APWO) and coordination with numerous parties including the base environmental staff (Mark Edson, Dustin Burton, Anthony Yamat), NAVFACSW environmental staff (Len Sinfield, Jessica Palmer), the NBSD FEAD (Commander Turner, Melissa Vincent, Kristin Olsen, James Sanchez), the LID Center and its subcontractors (Neil Weinstein, Bob Pitt, Kathleen Harrison, Courtney Wilson, Maggie McCormick) and the construction contractor (Mario and Rachel Portillo). As such, the demonstration was as much about building the technologies on an operational base as it was about the actual testing.

The lessons learned included the need for early and consistent communications with all involved parties. It cannot be emphasized enough how important it was to communicate with and get buy-in early in the process and then following up constantly as the process played out. This requires a champion of the work and for this we are ever-grateful to Dustin Burton for his personal efforts in promoting this project and following through on a near-daily basis with personnel on every step of the process. In particular, he worked diligently to get site approvals and helped to get a contract in place once the approval by the CO was given. Even with his diligent work the site approval process took two months and the construction contracting process an additional five months. Though these processes were expected to take time, they took considerably longer than expected.

Another lesson learned included the length of time it took to get a contract in place and its cost. To speed up the construction contracting process, the FEAD suggested the use of an IDIQ contract already in-place with NBSD. In the end the process took five months, which seemed to be no shorter of a timeframe than if an open bid process was used. As a result, the bid costs were based on construction elements that may not have been required for this specific project design. The original IGE of costs based on considerable expertise in building LID projects was exceeded by 17% ($28 thousand), which was negotiated down from the original bid that was $75 thousand or 46% higher. This outcome suggests that using a LID specific construction contract is warranted. Additionally, the cost of retrofitting LID appears to be substantially higher than building it in as part of new or redevelopment construction. A final lesson learned related to the contracting process was that the project was responsible for extra costs incurred to fix the Paver LID site when it experienced several failures caused by a previously unknown open sewer line located just below the site. The project was charged even though there was a lengthy Site Approval process that should have caught the issue and the site was now a part of NBSD.

The Biofiltration LID technology had drought tolerant plants installed, primarily as an aesthetic element. There was no watering originally planned for the site though it should have been planned at least in the first few months to establish the plants. However, it was possible to get the area watered as part of a NBSD landscaping contract at no extra charge. Even with watering, about 30% of the plants appeared to die about a year after they were planted.

Finally, these technologies are expected to be effective over the next 15 years with minimal maintenance. The Paver LID site should be subjected to power sweeping once or twice a year to minimize clogging. The Biofiltration site should be cleaned of trash on a regular basis and replanted during winter when there may insufficient rainfall to maintain the plants if it is to remain an aesthetically pleasing element of the base.

9. REFERENCES

AMEC. 2017. 2016/2017 Storm Water Annual Report For Industrial and Small MS4 Areas at Naval Base San Diego. San Diego, California Order NO. R9-2013-0064, NPDES PERMIT NO. CA0109169 (August). AMEC Project No. 5023-16-2500, DCN: KMJV-1418-0023-0041, San Diego, CA.

Clark, S. and R. Pitt. 2012. "Targeting Treatment Technologies to Address Specific Stormwater Pollutants and Numeric Discharge Limits." *Water Research* 46(20):6715–6730.

Environmental Protection Agency. 2002. "Clean Water Act" 33 U.S.C. §1251 et seq. (1972) 33 U.S.C. § 1251 et seq. 2002. Environmental Protection Agency, Washington, DC.

Katz, C., G. Rosen, and E. Arias. 2006. "Storm Water Toxicity Evaluation Conducted at Naval Station San Diego, Naval Submarine Base San Diego, Naval Amphibious Base Coronado, and Naval Air Station North Island." Space and Naval Systems Warfare Systems Center Pacific Technical Report 1938. San Diego, CA.

Katz, C., K. Sorensen, E. Arias, R. Pitt, and L. Talebi. 2014. "Modeling to Quantify Metal Sources in Stormwater Discharges at Naval Facilities (NESDI Project 455) Final Report and Guidance." Space and Naval Warfare Systems Center Pacific Technical Report 2077. San Diego, CA.

Katz, C. and E. Arias. 2014. Chollas Creek Storm Water Monitoring Study Final Project Report to NAVFAC SW. Augus.t Space and Naval Warfare Systems Center Pacific. San Diego, CA.

Naval Facilities Engineering Command. 2010. "Low Impact Development." UFC 3-210-10N (April). Naval Facilities Engineering Command, Washington, D.C.

Pitt, R. 2014. "The Use of WinSLAMM at Naval Bases to Predict Stormwater Pollutant Sources and to Identify Treatment Options." Space and Naval Systems Warfare Systems Center Pacific, San Diego, CA.

County of San Diego Department of Public Works. 2016. "County of San Diego BMP Design Manual for Permanent Site Design, Storm Water Treatment and Hydromodification Management: Storm Water Requirements for Development Applications." County of San Diego BMP Design Manual (February). County of San Diego Department of Public Works, San Diego, CA.

San Diego Regional Water Quality Control Board/. 2013. "Waste Discharge Requirements for the United States Department of the Navy Naval Base San Diego Complex San Diego County." Tentative Order No. R9-2013-0064; NPDES, No. CA0109169. California Regional Water Quality Control Board San Diego Region, San Diego, CA.

APPENDIX A

Site and Low Impact Development (LID) Technology Selection for Naval Base San Diego (NBSD) Commercial Area

Contract # N66001-15-F-0164 CDRK A0001

Date: May 5, 2015

Prepared for:
Energy and Environmental Sciences Group
Space and Naval Systems Warfare Center

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Geosyntec Consultants

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APPENDICES

INTRODUCTION

The following document describes the rationale and selection process for the siting and design elements of a Low Impact Development (LID) non-point source stormwater runoff Best Management Practice (BMP) demonstration project conducted by the Energy and Environmental Sciences Group of the Space and Naval Warfare Systems Center (SSC) Pacific under the Navy's Environmental Sustainability Development to Integration (NESDI) Program. The overall project goal is to demonstrate the effectiveness of LID Best Management Practices (BMPs) that can be used to mitigate the effects of non-point source stormwater runoff from commercial areas common to Navy facilities. The demonstration project will focus on the evaluation of the LID technologies at the NEX/Commissary commercial area of Naval Base San Diego (NBSD). Figure 1-1: Location of Study Area at NBSD shows the general location of the project area in relationship to the rest of NGSD.

Figure 1-2: Project Location Aerial shows the perimeter of the study area and the locations of the principal existing and proposed buildings, parking, open space, and infrastructure. The buildings include the Commissary and Annex, NEX, a proposed Navy Federal Credit Union building, and a group of office buildings to the north of the commercial areas. It also shows the two (2) main drainage areas within the study limits. The two (2) drainage areas that are outlined in
Figure 1-3: Project Drainage Areas and Storm Drain Infrastructure are subject to compliance requirements under the Total Maximum Daily Load (TMDL) program for discharges directly to the adjacent Chollas Creek and those under a combined Industrial Activities and Municipal Separate Storm Sewer Program (MS4) National Pollutant Discharge Elimination System (NPDES) permit. The main drainage area stormwater is discharged through the storm drain system to Outfall 72 and Outfall 73. These are shown on
Figure 1-3: Project Drainage Areas and Storm Drain Infrastructure and are located in the lower right hand corner of the exhibit. The LID pilot project will be located within these areas and will be used to evaluate the effectiveness of LID BMPs for mitigating the volume of stormwater and the volume and the concentration of copper (Cu), zinc (Zn), lead (Pb), and their resultant toxicity in the runoff. These metals are the key TMDL and NPDES permit metrics of concern identified in the permits.

This evaluation is based on the approximate drainage characteristics and geometry that would typically be used in similar locations and the local soils and hydrologic information at NBSD. It should be noted that there are some gaps in data or drawing information. There has also been some undocumented work, such as minor drainage repairs or repaving that may affect the final determination of BMP locations. The final locations may have to be adjusted during the engineering and design efforts of the next phase of this project. This may require additional topographic survey and utility investigations, as well as site visits. The technology focus of the evaluation was the use of bioretention technologies and media-based technologies. These were selected because they are the most effective at treating metals or can be modified to effectively treat metals. Other treatment technologies were included for a general comparison and reference on the effectiveness. Detailed calculations were also performed for the assessment of the most viable BMP project locations.

The report includes:

- An overview and description of the existing site features and drainage conditions.
- Methods and assessment criteria that are used to locate LID BMPs.
- The process for ranking and prioritizing the location and type of the LID BMPs for the study.
- Concept designs that include schematics, cross sections, plans, and a preliminary opinion of cost.
- Projections on the effectiveness of the LID technologies at mitigating the effects of the metals of concern.
- Recommendations on the monitoring locations that can be used to benchmark the effectiveness of the LID practices.
- Recommendations on the optimal project locations based on the selection criteria.

1.0 SITE FEATURES

The study area shown in Figure 1-1: Location of Study Area at NBSD and Figure 1-2: Project Location Aerial includes typical land uses that are representative of commercial and office areas found on naval installations. This includes parking lots, access roads and drives, rooftops, and landscaped areas. The stormwater runoff in the study area is captured by a series of grate inlets that are located in parking areas or open spaces, curb inlets that are integrated into the roadways and sidewalk edges, or manholes that collect runoff from roof drain systems. The runoff is collected in a network of storm drain pipes that eventually discharge to Chollas Creek. The storm drain system that collects water from the east portion of the study area is discharged at Outfall 72, as shown on Figure 1-3. The stormwater that is collected from west side is collected and discharged at Outfall 73. There are currently no stormwater management BMPs located within either of these drainage networks.

The proposed Navy Federal site shown in Figure 1-2: Project Location Aerial includes a bank building with drive-through windows, parking, sidewalk, and landscape areas. The site also includes LID bioretention swales and cells that collect and treat the stormwater runoff from the facility before it is discharged into the existing storm drain system in the NEX/Commissary area.

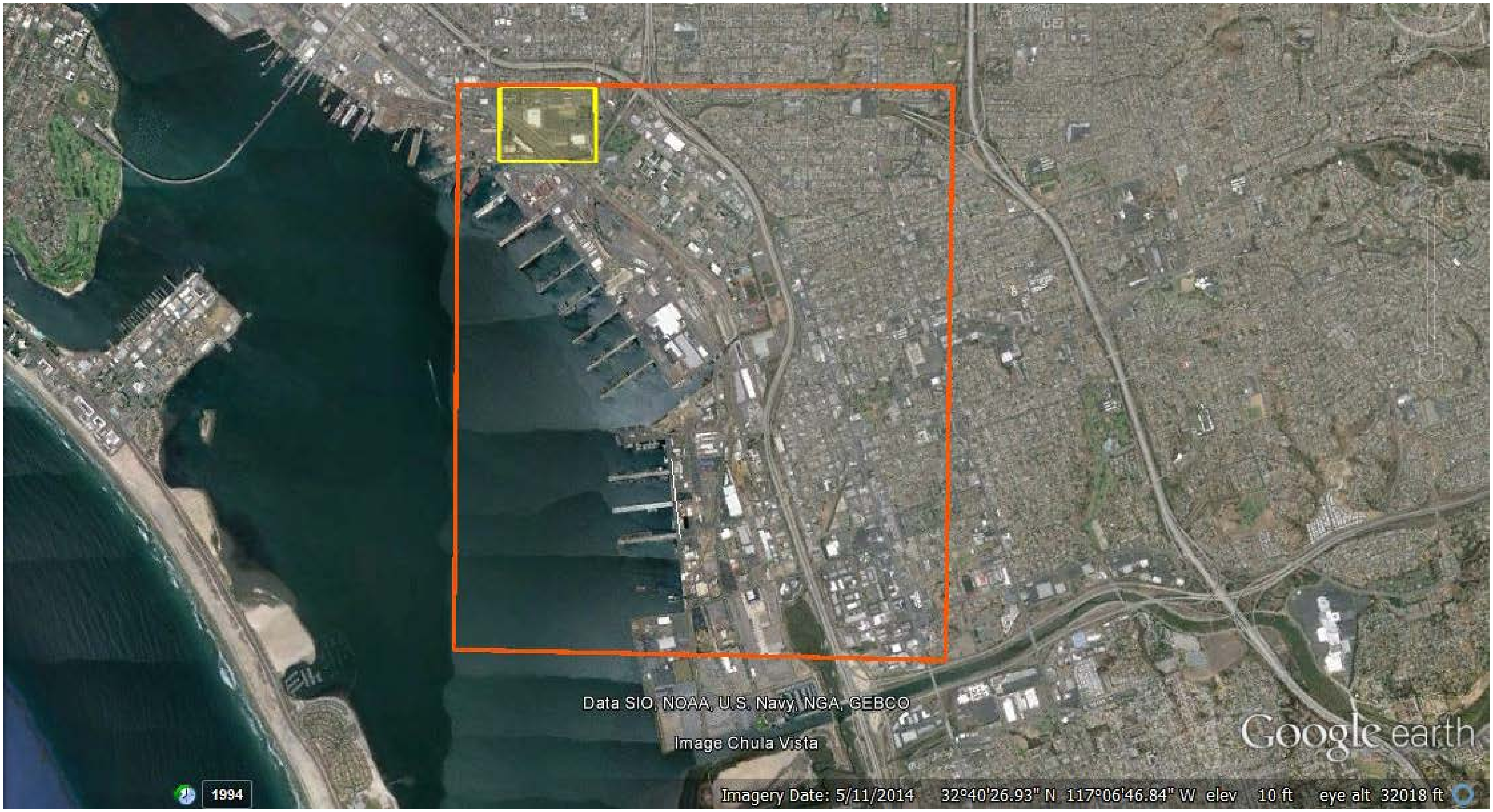


Figure 1-1: Location of Study Area at NBSD

Figure 1-2: Project Location Aerial

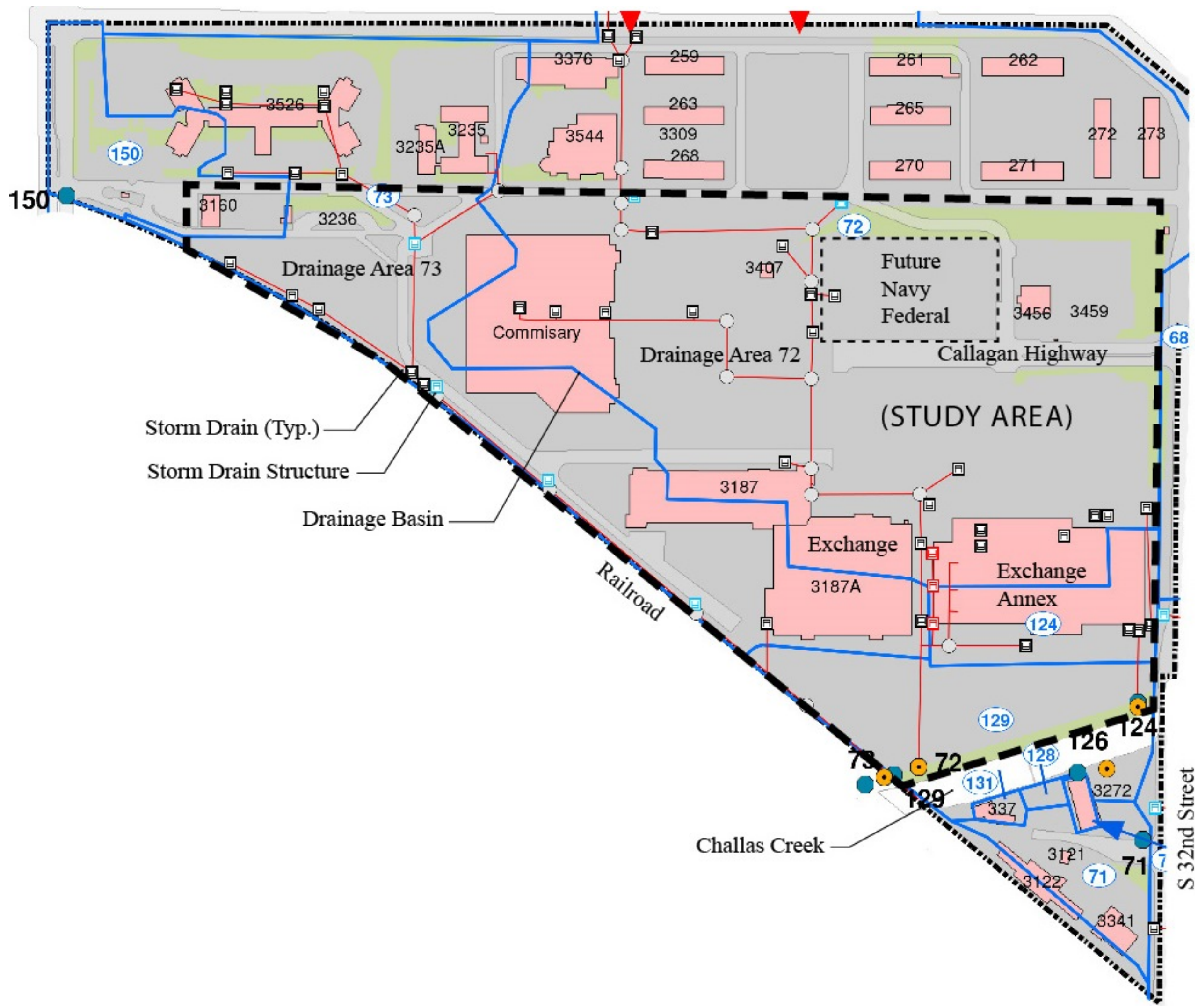


Figure 1-3: Project Drainage Areas and Storm Drain Infrastructure

2.0 METHODS

2.1 General LID Selection Criteria and Overview

This section describes the process for selecting project locations and appropriate BMPs. There are a wide range of LID technologies that can be used in commercial areas at Department of Defense and Navy installations. There is a general reference Uniform Facilities Criteria (UFC) on LID BMPs (Naval Facilities Engineering Command, 2010). That document includes guidance on the use and construction of commonly used LID BMPs so that they can meet federal, state, and local government stormwater management obligations and requirements. Some commonly used LID BMPs at commercial and office locations on DOD installations include:

- *Permeable Pavements* - Roads, parking areas, and walkways that are constructed of open graded asphalt, porous concrete, or bricks and blocks with gaps between them that let stormwater flow into underground aggregate sub-base for storage or infiltration.

- *Filter Strips* - Vegetated strips of grass, other vegetation, or media that filter pollutants from sheetflow runoff.

- *Bioretention Swales and Cells* - Areas that include specialized media and plants that filter, store, and infiltrate stormwater.

- *Green Roofs* - Watertight roofing systems that are overlaid with specialized planting media and plants that absorb or filter rainfall and store it for evapotranspiration.

- *Cisterns and Rain Barrels* - Tanks, vaults, and small-scale storage devices that capture rainfall for potable and non-potable uses, storage, or irrigation.

- *Infiltration Trenches and Dry Wells* - Areas that are excavated and filled with aggregates that are designed to store and infiltrate stormwater.

The selection of BMPs is an iterative process that requires the evaluation of a potential BMP location and the potential BMPs that can be used to meet the local objectives at that site. The evaluation and selection of the most appropriate stormwater controls are based on a wide range of factors. The effect of each of these factors can vary greatly for each project location under consideration. This includes physical features, costs, drainage characteristics and qualitative factors. Table 2-1: LID BMP Selection Criteria from UFC includes general guidance on the use, location, and maintenance criteria used for selecting and siting some commonly used LID BMPs.

Table 2-1: LID BMP Selection Criteria from UFC

Maintenance	Max. depth	Proximity to building foundations	Water Table/Bedrock	Slopes	Soils	Space required	
Low requirement, property owner can include in normal site landscape maintenance	2- to 4-ft depth depending on soil type	Minimum distance of 10 ft down gradient from buildings and foundations recommended	2- to 4-ft clearance above water table/bedrock recommended	Usually not a limitation, but a design consideration.	Permeable soils with infiltration rates > 0.27 inches/hr are recommended. Soil limitations can be overcome with use of underdrains.	Minimum surface area range: 50 to 200 ft^2. Minimum width 5 to 10 ft. Minimum Length 10 to 20 ft. Minimum depth 2 to 4 ft.	**Bioretention**
Low requirement	6- to 10-ft depth depending on soil type	Minimum distance of 10 ft down gradient from buildings and foundations recommended	2- to 4-ft clearance above water table/bedrock recommended	Usually not a limitation, but a design consideration. Must locate down gradient of building foundations.	Permeable soils with infiltration rates > 0.27 inches/hr are recommended.	Minimum surface area range: 8 to 20 ft^2. Minimum width 2 to 4 ft. Minimum Length 4 to 8 ft. Minimum depth 4 to 8 ft.	**Dry Well**
Low requirement, routine landscape maintenance	Not applicable	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Generally not a constraint.	Usually not a limitation, but a design consideration.	Permeable soils perform better, but soil not a limitation.	Minimum length of 15 to 20 ft.	**Filter/Buffer Strip**
Low requirement, routine landscape maintenance	Not applicable	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Generally not a constraint.	Swale side slopes: 3:1 or flatter. Longitudinal slope: 1.0% minimum; maximum based on permissible velocities.	Permeable soils provide better hydrologic performance, but soils not a limitation. Selection of type of swale, grassed, infiltration or wet is influenced by soils.	Bottom width: 2 ft minimum, 6 ft maximum	**Swales: Grass, Infiltration, Wet**
Low requirement	Not applicable	Not a factor	Generally not a constraint.	Usually not a limitation, but a design consideration.	Not a factor	Not a factor	**Rain Barrels**
				Not a factor	Not a factor	Not a factor	**Cistern**
Moderate to high	6- to 10-ft depth depending on soil type	Minimum distance of 10 ft down gradient from buildings and foundations recommended	2- to 4-ft clearance required	Usually not a limitation, but a design consideration. Must locate down gradient of building foundations.	Permeable soils with infiltration rates > 0.52 inches/hr are recommended.	Minimum surface area range: 8 to 20 ft^2. Minimum width 2 to 4 ft. Minimum Length 4 to 8 ft.	**Infiltration Trench**

Source: Low-Impact Development Design Strategies, prepared by Prince George's County, Maryland

Each installation has to modify the process for the selection and operation of LID BMPs. A federal, state, or local regulatory agency that administers the stormwater permit will have specific stormwater management BMP design standards and specifications for sizing, location, configuration, materials, and maintenance. When there are specific targeted stormwater pollutant discharge limits, such as the treatment of runoff from metals, the BMP selection criteria process needs to consider the effectiveness of the BMP at reducing the concentration of the pollutant while still meeting the general stormwater treatment requirements. There are also site-specific physical and infrastructure considerations, such as soils and groundwater conditions or storm drain infrastructure capacity. Installations will also have specific operational requirements that are based on facility master plans or construction and operations policies. Some of the key requirements, or constraints, for siting and installing LID at the NBSD site include:

- BMPs should be located away from buildings because of maintenance and force protection considerations
- Rooftop BMPs should not be considered due to maintenance requirements
- The number of parking spaces that are removed or impacted should be minimized
- High aesthetics and educational value
- Low maintenance requirements

This location also has some opportunities for the use and study of the LID BMPs that will be located at the Navy Federal site. There is potential to monitor the effectiveness of one or more LID BMPs that treat runoff from the proposed parking and building areas.

2.2 Review of Site Drawings and Utility Information for NEX and Commissary Areas

The first step in the evaluation and selection of LID BMPs for the project is to develop base maps and gather information on physical features that will be used in the assessment process. The project team reviewed a series of GIS maps, construction documents, and as-built documents for the NEX and the Commissary buildings and associated infrastructure. The review was focused on determining drainage areas and the extent of the storm drain system and locations of existing underground utilities for potential conflicts with the pilot project construction. It should be noted that there are some gaps in data or drawing information. There has also been some undocumented work, such as minor drainage repairs or repaving that may affect the final determination of BMP locations. This may have to be resolved during the final design phase of the research effort with additional site visits. Figure 2-1: Composite Site and Utility Map shows the utilities and drainage areas as map, developed from the drawings of record. The project team also conducted a field evaluation of the drainage structures along the railroad and some of the existing inlets within the parking areas in order to determine the elevations of the drainage structures, such as invert locations of manholes and inlets, and the approximate sizes of the storm drain pipes. The prior field evaluation consisted of locating the structures using GPS and then measuring the pipe sizes and inverts of the storm drain system when it was accessible. Some of the structures were inaccessible due to the structure tops being inoperable. No vertical control and pipe slopes were established. This information is included in Appendix A: Additional Drainage Structure Information.

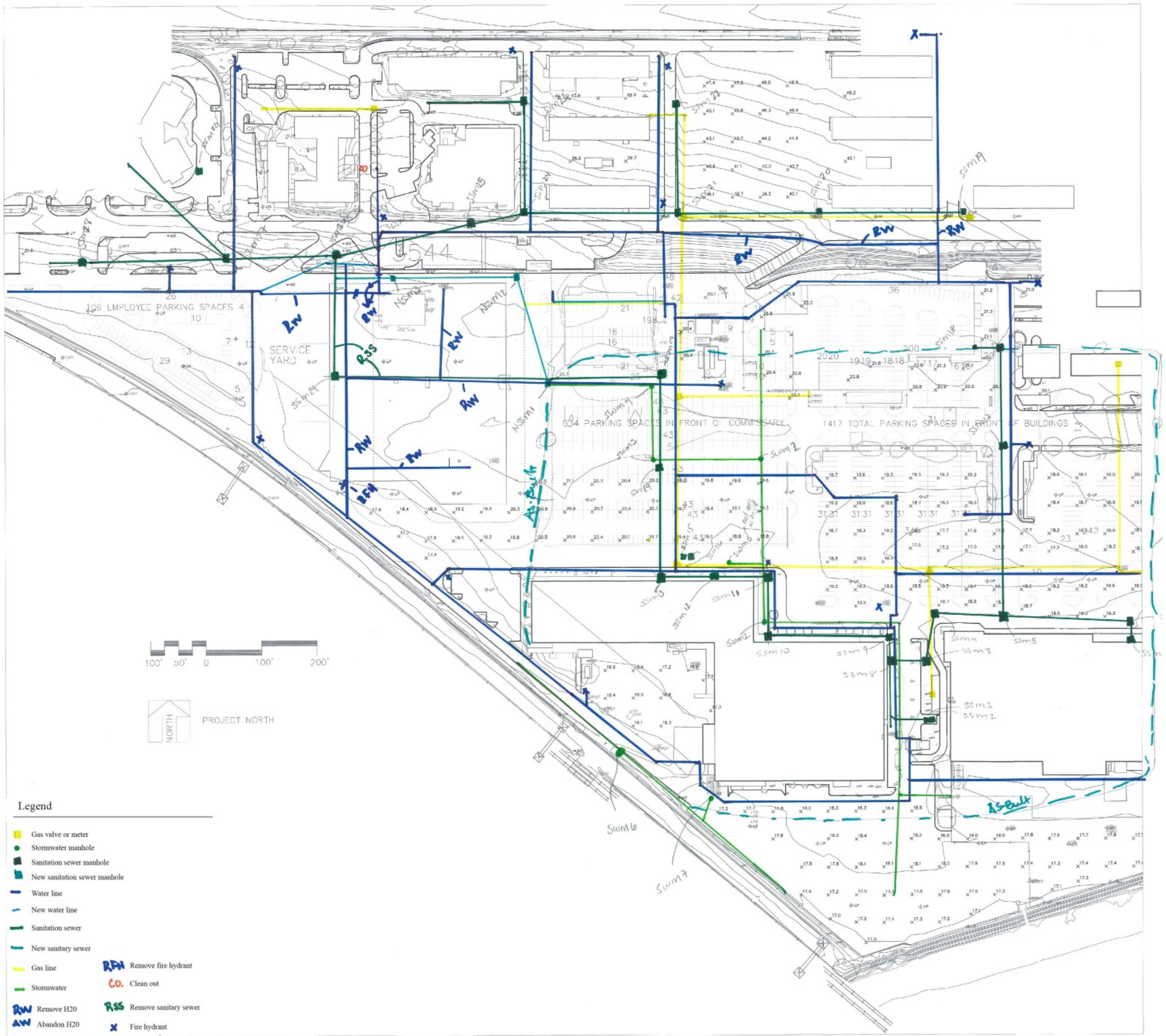


Figure 2-1: Composite Site and Utility Map

2.3 Navy Federal Construction Site

A proposed Navy Federal Bank building is planned for the area shown in Figure 2-2: Navy Federal Site. The planned construction includes implementation of several LID elements that may lend this site as a potential monitoring location. The projected time for the anticipated completion of this facility is late 2015.

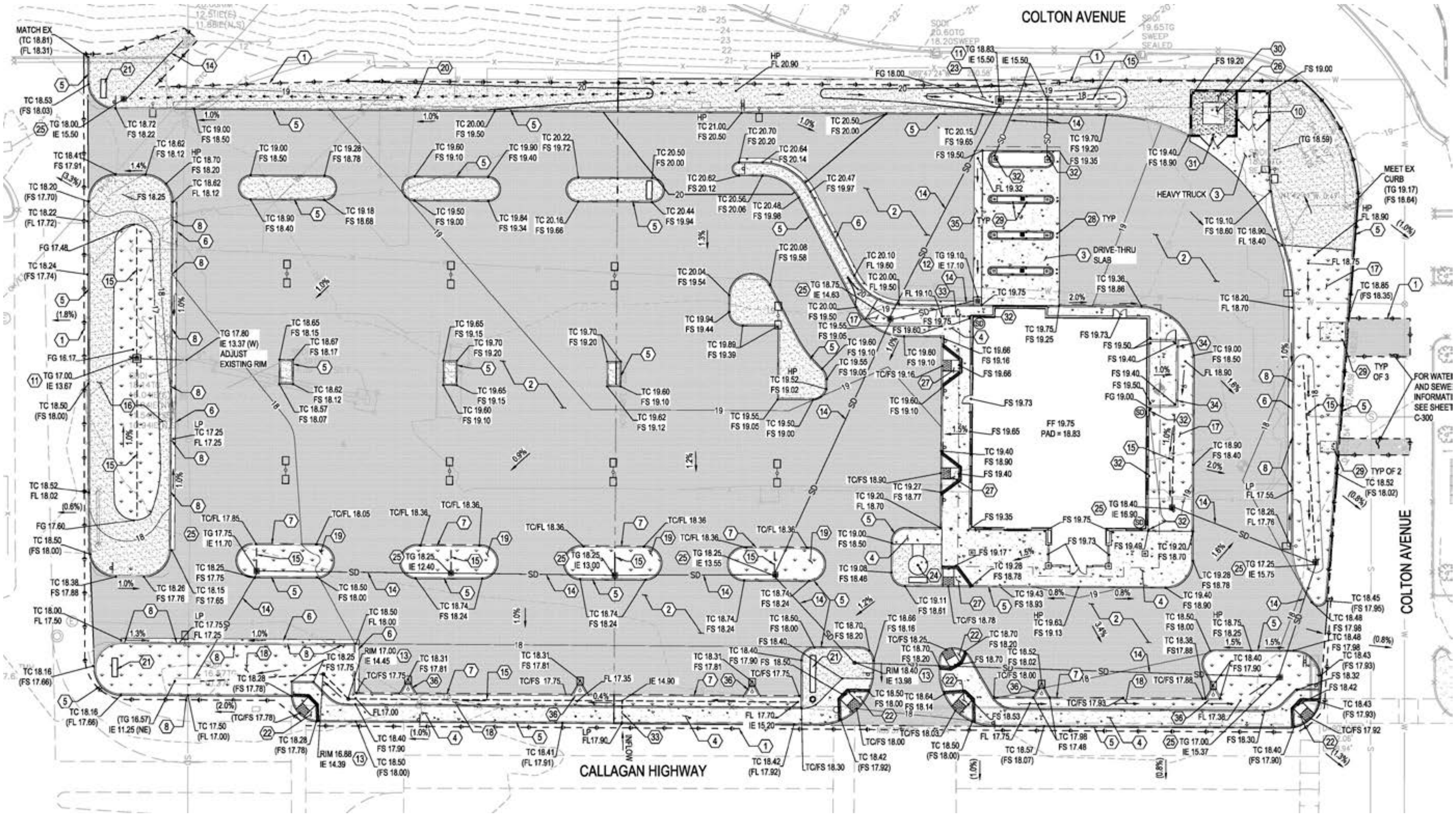


Figure 2-2: Navy Federal Site

The project team reviewed the site plans, geotechnical reports, and stormwater management calculations for the facility. The information reviewed was developed from 2013 to 2015. The review is summarized below:

- *Geotechnical Report:* Soils are critical in the design and operation of stormwater controls, especially those where infiltration is desired. Very low infiltration capacities require much larger facilities, and/or poorer treatment compared to areas with moderate or high infiltration capacities. Therefore, preference would be given to areas having soils with higher infiltration rates. The site is on fill that varied in depth from approximately three (3) to seven (7) feet. The report generally described the fill soils as a medium gray brown, clayey sand that was slightly moist and medium dense in consistency. The natural depositional soils below the fill are medium gray brown, medium grained silty sandstone that was slightly moist and medium dense. Interbedded siltstone and clay stone beds and zones rich in shells were also encountered. The latter contained zones of soft silt stone below the groundwater table. The geotechnical report determined that the depth to groundwater was approximately sixteen (16) feet from the soil borings. The depth may fluctuate with the tide or seasonally. The potential for perched water tables to develop during periods of prolonged rainfall has also been identified. The fill soils were generally classified under the Unified Soil Classification System (USCS) as Clayey Sand (SC). The native soils were generally classified as Silty Sands (SM). Both of these soils have low potential for infiltration (under 0.5 inches per hour). Percolation tests, which are used in the sizing and design of stormwater infiltration BMPs, were not conducted during the investigation. The geotechnical report recommended over excavation for proposed new pavement to account for any poor structural properties of the undocumented fill area. It also recommended minimal surface slopes and providing adequate drainage away from foundations. This information can be used to generally characterize the soils in the project areas and are appropriate for this planning level study. Additional soils and geotechnical information should be obtained for the final design phase. The relevance of this information is that the remainder of the project area should have a sufficient buffer between ground water and any shallow or medium depth BMP.

- *Site and Infrastructure Plans and Stormwater Management Calculations:* The Navy Federal construction project includes multiple bioretention cells, bioswales, swales, and landscape areas. The facilities were sized to meet the City of San Diego Stormwater Design Manual water quality standards. The soils used in the drainage analysis were classified as Hydrologic Soils Group (HSG) D. These are poorly drained soils with a low potential for infiltration. This is confirmed by the soils report. All of the BMPs were designed with underdrains and/or inlets that discharge to the existing storm drain system adjacent to the property. This allows for the facilities to dewater so that there is sufficient storage for the next storm and so that the facilities do not become swamped and anoxic; a state that would result in the death of any of the plants in the facility, cause aesthetic concerns, and increase the presence of nuisance insects.

2.4 Project and BMP Site Selection Criteria

The evaluation and selection of pilot project locations are based on a wide range of factors. The effect of each of these factors can vary greatly for each project location under consideration. The project team used a combination of quantitative factors that are based on the physical features, costs, and drainage characteristics and qualitative factors that are based on the experience of the project team in constructing pilot and monitoring projects to select the potential sites for further consideration and evaluation of potential BMPs for the location. In addition to the site-specific requirements described earlier, the most desirable characteristics for a project location are included in the list below.

- The site is representative of land use (e.g. traffic volume, roof type, etc.).
- The surfaces (e.g. parking, roofs, etc.) are in good condition.
- There are no excessive unstabilized sediment loads or future construction activities that may drain to the site.
- There are no potential storage areas, loading areas, or fueling areas that can have excessive metals loading that drain to the site.
- The surface drainage area can be clearly defined.
- The storm drain outfall for the area can be clearly defined.
- The condition of the storm drain pipes is known.
- There is opportunity to install monitoring equipment in an existing storm drain structure and it is accessible in a safe manner.
- There are no underground utilities that require special protection or relocation.
- A reference monitoring site with similar drainage characteristics and land use that can be monitored is in close proximity.
- Monitoring equipment (e.g. shelters, flowmeters) can be accessible at the surface and placed in steel security boxes that do not hinder site activities. Available electrical power at the monitoring location is a bonus, but not mandatory.
- The subsurface soil conditions are known and suitable for the proposed stormwater control. The groundwater table is well below the bottom of the stormwater control BMP (and drainage system) with minimal potential for groundwater mounding interfering with the infiltrating water from the stormwater control or underdrains. Groundwater contamination potential is also minimal.

A list of undesirable characteristics is as follows:

- The site is not representative of the typical land use (e.g. traffic volume, roof type, etc.).
- The surfaces (e.g. parking, roofs, etc.) are in fair or poor condition.
- There are unstabilized sediment loads or future construction activities that may drain to the site.
- There are potential storage areas, loading areas, or fueling areas that can have excessive metals loading that drain to the site.
- The surface drainage area is poorly defined or too flat, or the downgradient location for the stormwater control BMP is poorly situated in relationship to site activities.

- The storm drain outfall area cannot be clearly defined. The area ratio is too large for the available area for the stormwater control and the surface flow lengths to the device are too long for the proposed BMP technology.
- The condition of the storm drain pipes is poor or unknown. The pipes may be submerged in the groundwater with likely infiltration. Seepage losses in a storm drain in poor condition can also cause decreased flows before the monitoring location. There is evidence of flow during dry weather.
- There are no opportunities to install monitoring equipment in an existing storm drain structure.
- Installation of monitoring equipment would be very difficult in an existing storm drain structure because it is too deep or hard to access, is in an unsafe location, the storm drain outfall or connection to the system is complex, or there is potential for backup of stormwater due to downstream pipes being undersized or tidal influences.
- There are underground utilities that require special protection or relocation (likely a fatal flaw for this location due to costs and involvement of utilities).
- A reference monitoring site is not available in the proximity of the site.
- Monitoring equipment (e.g. shelters, flowmeters) can only be placed in high traffic areas at the surface. Electrical power is not available, or would be difficult to install.
- The subsurface soil conditions and location of the groundwater table are unknown or adverse to the design of the stormwater control BMP. Groundwater contamination potential is high or unknown. Contaminated groundwater under the site may be adversely affected by increased stormwater infiltration (increasing movement to unwanted locations).

3.0 PROJECT LOCATION AND BMP TECHNOLOGY SELECTION

3.1 Project Location Criteria

Twenty-seven (27) potential sub-drainages were evaluated for locating potential pilot projects. These locations were selected because they are at or near existing storm drain structures (e.g. inlets, manholes, swales, etc.) or existing storm drain pipes. This was done to minimize the amount of drainage infrastructure that would be needed to construct the pilot projects and because these are generally locations where stormwater is collecting and can be treated. Figure 3-1: Potential Pilot Project Locations is a map of the project locations.

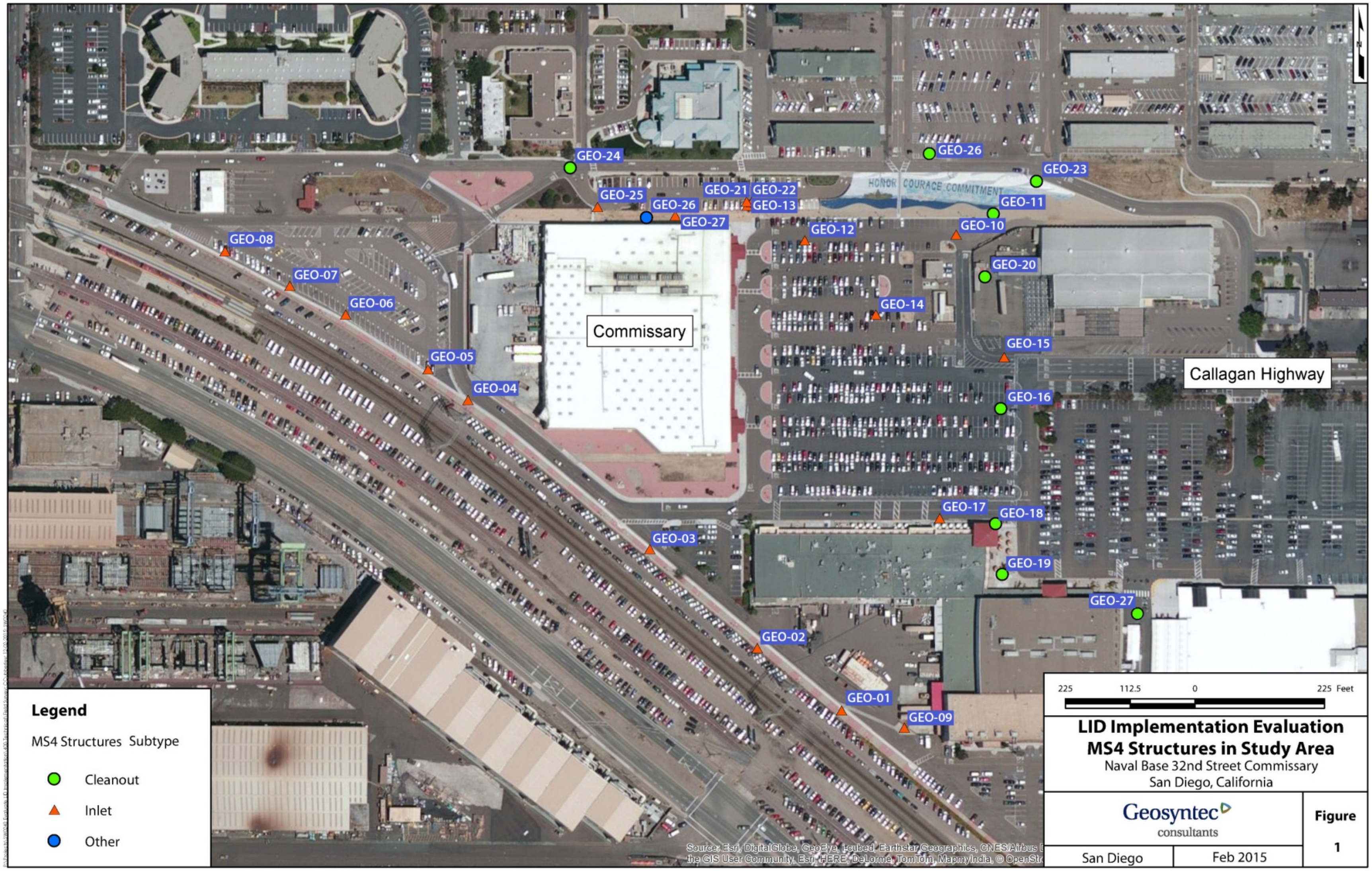


Figure 3-1: Potential Pilot Project Locations

A summary of the analysis for each of the locations under consideration is shown in Table 3-1: Project Location Analysis. The comments from the initial site investigation and field observations are also listed in the table.

Table 3-1: Project Location Analysis

No.	Description	Comment
1	Curb inlet along S 29th St. Located in SW portion of the facility.	Sump condition with concrete channel across road. Difficult to flank with devices on sides. Potential to do shallow inlet w/sidewalk slab on top and put some treatment between fence and landscape and tie back in.
2	Grate with drop inlet, located adjacent to fence line at southern end of concrete swale.	Could do shallow inlet/slab sidewalk and slope treatment that ties back into lower grate. System is shallow. Narrow sidewalk.
3	Curb inlet along S 29th St. Located in SW portion of facility, along fence line.	Small area with slope and pipe is not deep.
4	Curb inlet along S 29th St. Located in SW portion of facility.	Possible flanking facilities on flat area behind sidewalk. Difficult to engineer. Use slab/sidewalk inlet. Shallow depth to pipe. Also heavy truck use.
5	Catch basin in NW parking lot of facility.	It looks like parking area drains to inlet (need to confirm). Good to retrofit around inlet with island. Could relocate sidewalk.
6	Catch basin in NW parking lot of facility.	Good for retrofit around inlet but some parking spaces will be lost. Shallow system.
7	Catch basin in NW parking lot of facility.	Narrow space and small drainage area. Need to relocate parking. Shallow System. Potential monitoring reference location.
8	Catch basin in NW parking lot of facility.	Space constraints and concern about drainage from fueling area.

No.	Description	Comment
9	Catch basin in NW parking lot of facility.	May have some excessive loads from storage area. Depth to pipe is shallow May have access/traffic/turning issues. May need to be protected
10	Catch basin in North parking lot of facility.	Could locate facility in island and underdrain to inlet. Need to check slopes around parking area - may need curb. Need to check utility box in island.
11	Cleanout in gravel in NE portion of facility.	Not a significant drainage area.
12	Catch basin in North parking lot of facility. Pipe enters bottom of basin.	Too shallow and difficult to work in due to location in drive aisle.
13	Catch basin in gravel swale at SE corner of commissary. Pipe enters bottom of basin.	Limited drainage area and unstable soils around the perimeter. Need to check DA.
14	Catch basin in North parking lot of facility.	Good location. Need to remove 4 to 6 parking spaces. Check drainage areas.
15	Catch basin in North parking lot of facility.	Location appears to be in traffic way.
16	Cleanout in North parking not of facility.	Could use as tie in but in traffic and far from islands.
17	Curb inlet along road in front of the food court.	Too close to walk and drive.
18	Cleanout at NE corner of food court. 2nd pipe discharging into cleanout.	Turning MH no space.
19	Manhole cover with 2 pipes. In sidewalk @ NEX. Manhole cover marked with an "S".	Could tie trench drains with media around patio into this but it would be expensive and not convenient.

No.	Description	Comment
20	Cleanout in newly paved credit union parking lot.	Appears to be tie-in point for Navy Federal construction. Need to check site plans. It looks like parking will eventually be removed.
21	Catch basin east of 3629 Bld.	Shallow and will effect parking.
22	Curb Inlet along Colton Ave.	Potential tree box filters. Limited space.
23	Former curb inlet, redevelopment has occurred, manhole still accessible.	Good location to tie into and capture road runoff. Install new inlet and bioswale. Small drainage area and loss of parking.
24	Cleanout in Colton Ave and S 29th St.	In traffic.
25	Catch basin north of Commissary.	Maybe small shallow trench device. Have to work around wall. Need to determine outfall. Small drainage area.
26	Existing storm drain line.	Need tie into with manhole. Potential utilities. Good drainage area.
27	Existing trench drain and inlet in front parking area.	Utility conflicts and parking needs to be reworked.

3.2 Project Location Selection

Further desktop evaluation of each potential location was conducted using the pilot project area selection criteria. Each site was benchmarked against the criteria. The evaluation is summarized in Table 3-2: LID Pilot Project Location Analysis. Four (4) candidate pilot project locations were selected as the most favorable areas for further evaluation based on the selection criteria. The other 23 potential locations had one or more deficiencies. The candidate locations are highlighted in Table 3-3: LID Pilot Project Location Evaluation and shown in Figure 3-2: LID Pilot Project Locations.

Table 3-2: LID Pilot Project Location Analysis

	Pilot Project Location Number																										
Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	●	○	○	○	●	●	○	○	○	○	○	○	○	●	○	○	●	○	○	○	○	○	●	●	○	●	○
2	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	○	●	●	●	●	●	●	●	●	○
3	●	●	●	●	●	●	●	●	●	○	○	●	○	●	○	○	○	○	●	●	●	●	●	○	○	●	○
4	○	○	●	○	●	●	●	●	○	○	●	●	○	●	●	●	●	○	○	○	●	●	●	○	●	●	○
5	○	○	●	○	○	●	○	○	●	○	●	○	○	●	○	○	●	○	○	●	○	○	○	○	○	○	●
6	●	●	●	●	●	●	●	●	●	○	●	○	○	●	●	●	●	○	○	●	●	●	●	●	●	●	○
7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
8	○	○	○	●	●	○	○	○	○	○	●	●	○	●	○	○	○	○	○	○	●	●	●	○	○	●	○
9	●	●	●	●	●	●	●	●	●	●	○	○	○	●	○	○	○	○	○	●	○	○	●	○	○	●	○
10	●	●	●	●	●	●	●	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	●	○	○	●	○
11	●	●	●	●	●	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	●	○	○	●	○
12	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○
13	○	○	○	○	●	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	●	○	○	●	○

Criteria

1. Representative of land use
2. Surfaces in good condition
3. No excessive sediment loads
4. No hot spots
5. Defined drainage areas
6. Known outfall
7. Existing storm drain condition known
8. Opportunity for monitoring
9. No utility conflicts
10. Comparison to reference monitoring
11. Monitoring equipment accessibility
12. Favorable soils conditions
13. Constructability

Table 3-3: LID Pilot Project Location Evaluation

No.	**Criteria**	LID Pilot Project 1	LID Pilot Project 2	LID Pilot Project 3	LID Pilot Project 4
Location		5	14	23	26
1	Representative of land use	●	●	●	●
2	Surfaces in good condition	●	●	●	●
3	No excessive sediment loads	●	●	●	●
4	No hot spots	●	●	●	●
5	Clearly defined drainage areas	○	●	○	○
6	Known outfall	●	●	●	●
7	Existing storm drain condition known	○	○	○	○
8	Opportunity for monitoring	●	●	●	●
9	No utility conflicts	●	●	●	●
10	Comparison to reference monitoring	●	●	●	●
11	Monitoring equipment accessibility	●	●	●	●
12	Favorable soils conditions	○	○	○	○
13	Constructability	●	●	●	●

Key:
●Meets criteria
○Only partially meets criteria

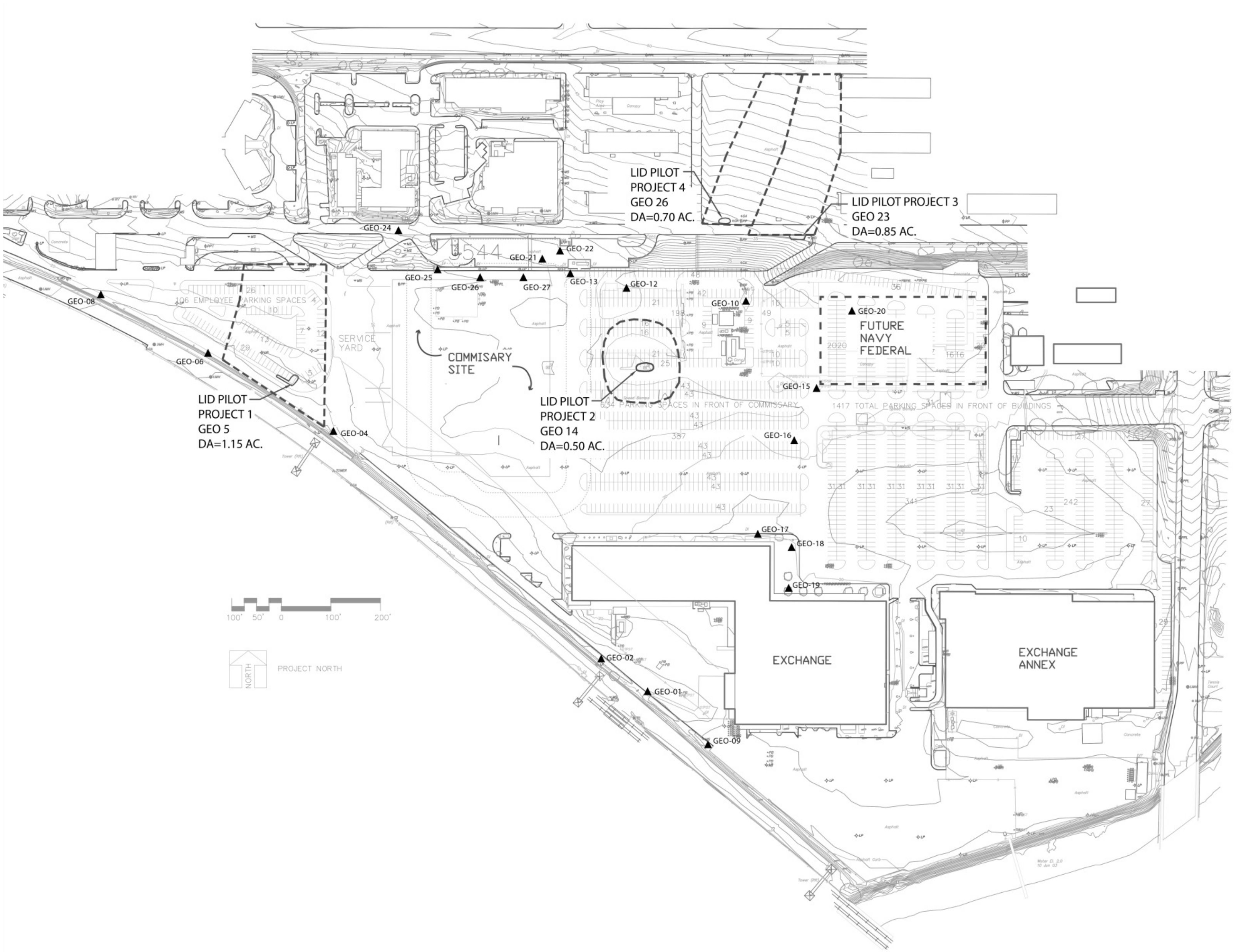


Figure 3-2: LID Pilot Project Locations

3.3 LID Technology Selection

LID bioretention media-based technology (filtration, sorption, and ion exchange are the unit treatment processes present in these devices) will be the most effective and efficient way to mitigate and reduce the pollutant load and impacts from metals (Clark, 2012). It is a proven technology and accepted as a stormwater mitigation technology by regulatory agencies. Bioretention media-based systems are also actively being researched and the body of knowledge and reliability of these systems is increasing so that there is more predictability in the outcomes or effectiveness of the treatment. The following is a list of key criteria for the final selection of bioretention media-based BMPs. Table 3-4: LID Technology Selection is a summary of how each proposed project location compares to the criteria.

1. Improper maintenance may not disrupt or skew the results.
2. The BMP will perform without the plants being thoroughly established or stressed under drought conditions.
3. The BMP will be configured to fit the available location and provide the desired level of control.
4. There is a sufficient or appropriate drainage area for the technology to perform and be monitored.
5. There is a sufficient knowledge base of data/monitoring results for similar projects or allied technologies that can be used to calibrate or evaluate the monitoring results.
6. Local materials or vendors are available to construct proprietary and/or non-proprietary BMPs through a design/build process.
7. The stormwater control BMP design can be adapted to the localized conditions.
8. The stormwater control BMP parameters and processes can be analyzed using WINSLAMM.
9. The BMP is resilient or can be repaired if it is subjected to high sediment loads or poor maintenance.
10. Is there a preference for proprietary, non-proprietary, or experimental BMPs?
11. The maintenance procedures and life cycle costs of the technology are predictable.
12. The City of San Diego BMP manual can be used to analyze the design.
13. There are no potential long-term issues with BMPs after the monitoring period and the end of the study period (e.g. extensive maintenance, pollution accumulation, etc.).
14. The area should be easily decommissioned at the close of the project, if desired.
15. There are no potential excessive maintenance requirements or specialized training required if the stormwater control BMP is to remain.

Table 3-4: LID Technology Selection

Criteria	LID Pilot Project 1	LID Pilot Project 2	LID Pilot Project 3	LID Pilot Project 4
Can function with improper maintenance	○	○	○	○
Can perform without plants established	●	●	●	●
Can be properly configured	○	○	○	○
Appropriate drainage area	○	●	○	○
Sufficient monitoring information	●	●	●	●
Vendor availability	●	●	●	●
Adaptability to local conditions	●	●	●	●
Can be analyzed with WINSLAMM	●	●	●	●
BMP is resilient	○	○	○	○
Non-proprietary or proprietary	●	●	●	●
Predictable maintenance	●	●	●	●
Can be designed with local criteria	●	●	●	●
No long-term life-cycle issues	●	●	●	●
Can be decommissioned	●	●	●	●
No excessive training	●	●	●	●

Key:
●Meets criteria
○Only partially meets criteria

The project team conducted a study of the drainage characteristics and the potential performance of a range of BMPs that can be applied at the potential locations. The evaluation was conducted using the Windows Source Loading and Management Model (WinSLAMM model) (Pitt, 2014) and the long-term rainfall data from the San Diego Airport for the 62 year period from 1951 through 2013. The model was used to estimate the performance of potential BMPs at reducing the annual loads of copper, lead, and zinc for the potential pilot projects. Additional water quality calculations focusing on site-specific characteristics and actual designs of the control practices are performed for the selected final pilot project site(s). The focus of the assessment was on the use of bioretention and media-based technologies, as they are the most effective at treating metals or can be modified to effectively treat metals. Other treatment technologies such as street sweeping, green roofs, swales, and various proprietary devices were evaluated but were excluded because of space considerations, appropriateness, operations considerations, and limited effectiveness for treatment of metals.

Two bioretention cell depths, surface areas, and storage volumes were evaluated in order to determine the approximate appropriate size of the pilot projects for planning purposes. The depth of the bioretention cells ranged from a deep cell of five (5) feet to a shallow cell of two and one half (2.5) feet deep. Underdrains were included because infiltration capacity of the underlying native soils, estimated from regional soils reports, indicated poorly drained soils. It should be noted that there are some boundaries, or general rules, that are applied to the sizing criteria for

bioretention that are used to determine the pilot project locations and configurations. Generally, the drainage area should be less than one-half (1/2) acre of imperviousness for cells that are less than 2,000 square feet. The percentages of impervious surfaces to bioretention cells that are less than 1 or 2 percent may cause inundation and saturation of the system that may affect the performance. Given these criteria, a bioretention cell should be approximately 2,200 square feet per acre or approximately 45 ft x 45 ft in size per one-half acre. Most cells are designed to include one to three feet of media, as that is where the most effective treatment activity occurs. Additional depth of media, gravel, or pipes can be used for supplemental detention storage or for holding runoff until it infiltrates. It should also be noted that some of the candidate project locations have a much larger ratio of drainage area to BMP size as recommended in the San Diego County Stormwater Design Manual. This is because of the limitations on location and size due to the existing physical and operational constraints in the study area. Some of the larger flows may bypass the system and the system may require a larger sized underdrain to adequately dewater the system for the next flow or for performance.

The water quality loading and BMP performance, or removal efficiency, were estimated from a previous study (Pitt, 2014). The results are normalized in terms of the percentage ratio of the area of the treatment device in relationship to the amount of paved drainage area. The analysis included an estimate of the amount of volume that is reduced through infiltration, evaporation, and evapotranspiration; the amount of solids that are filtered by the media; and the overall reduction of concentration in the effluent for copper, zinc, and lead. The reduction in volume, shown in Figure 3-3: Percentage Runoff Volume Reduction, is important to determine the reduction of soluble and particulate metals that must be filtered out or treated by the bioretention media. Figure 3-4: Percentage Particulate Mass Reduction is important to determine the reduction in particulate forms of the copper that can be captured by the cell. Figure 3-5: Copper Reduction Rates is a graph comparing the effectiveness of the two (2) depths using two (2) different types of underdrain systems for removing copper. One underdrain system uses a 3-inch discharge pipe and the other uses SmartDrain™, which is an inexpensive proprietary underdrain device that has a very low flow rate to encourage infiltration. The graph shows the percentage removal of the flow as a result of the relationship between the percentage of LID control to the amount of impervious area. The results for zinc and lead are shown in Figure 3-7: Zinc Removal Rates and Figure 3-8: Lead Removal Rates. These graphs show that there are significant gains in treatment efficiency as the percentage of BMP coverage when compared to the overall amount of impervious increases. These are conservative estimates of effluent copper, zinc, and lead concentrations and only reflect the removals of these metals based on particulate-bound metals. The biofilter media can also affect the removals of the filtered forms of these metals resulting in further overall reductions. Filtered forms of the metals pass through a 0.45 to 2 µm filter and may include metal ions of different charges, colloidal forms of the metals, or metal complexes, which all behave differently in biofilter media. The expected residence time of stormwater in contact with the biofilter media is about 5 to 10 hours for these sites, which maximizes the capture of the filtered forms of the metals in the media. The process is further described below.

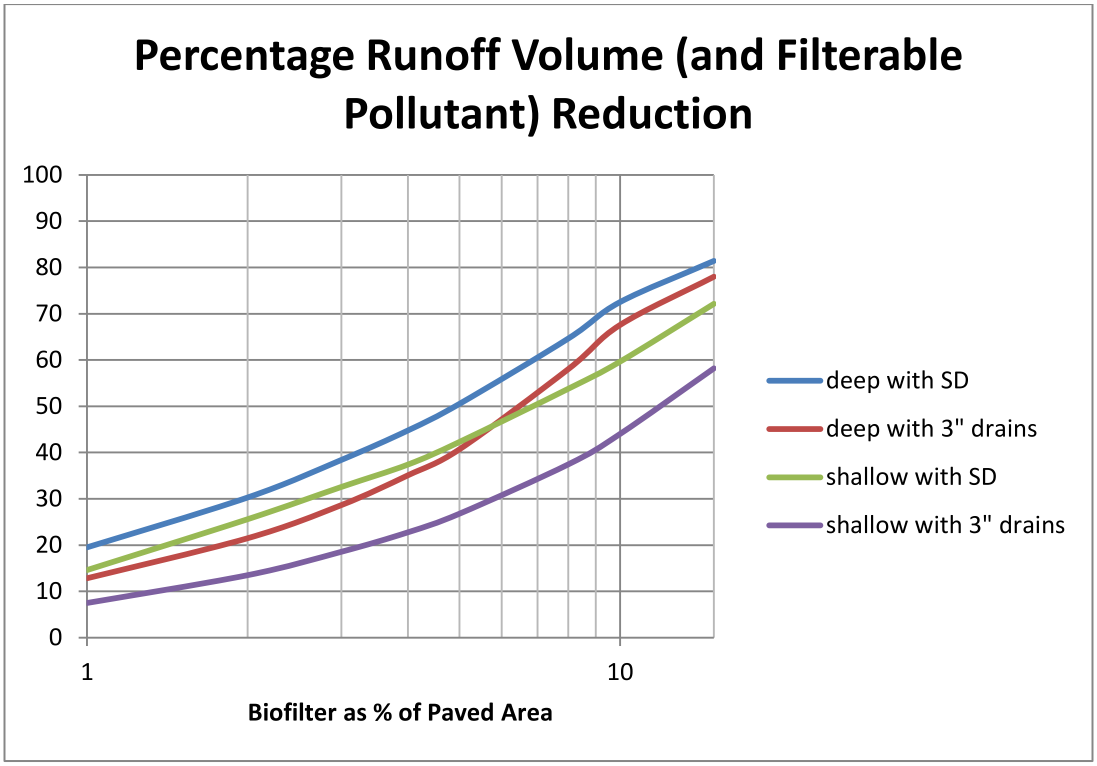


Figure 3-3: Percentage Runoff Volume Reduction

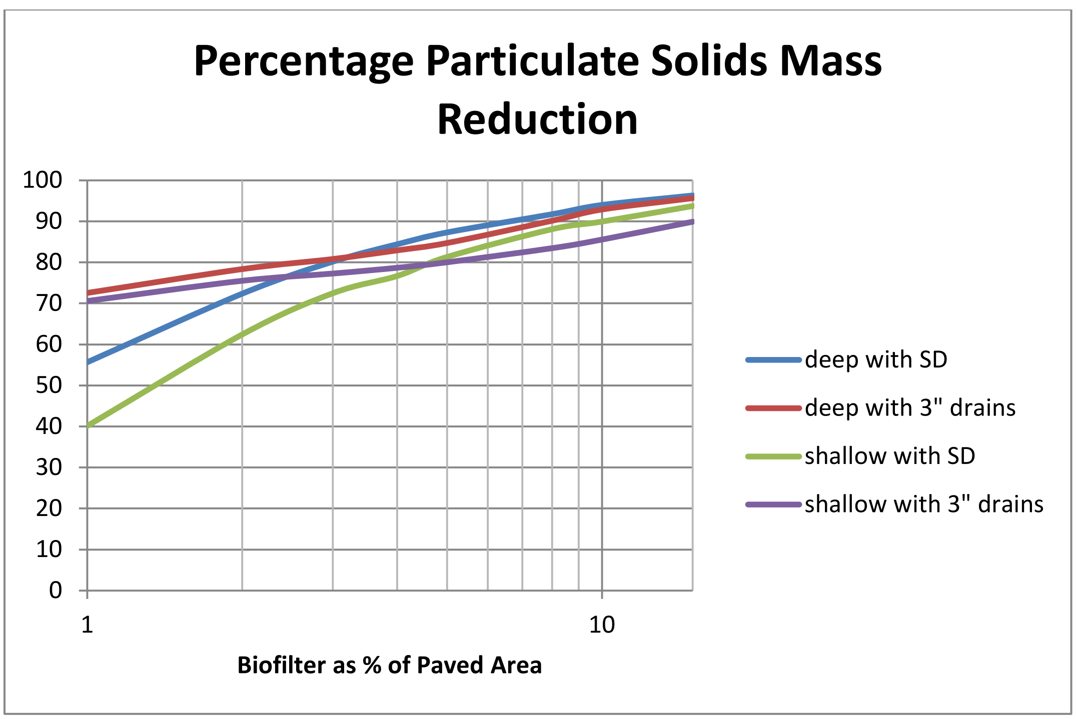


Figure 3-4: Percentage Particulate Mass Reduction

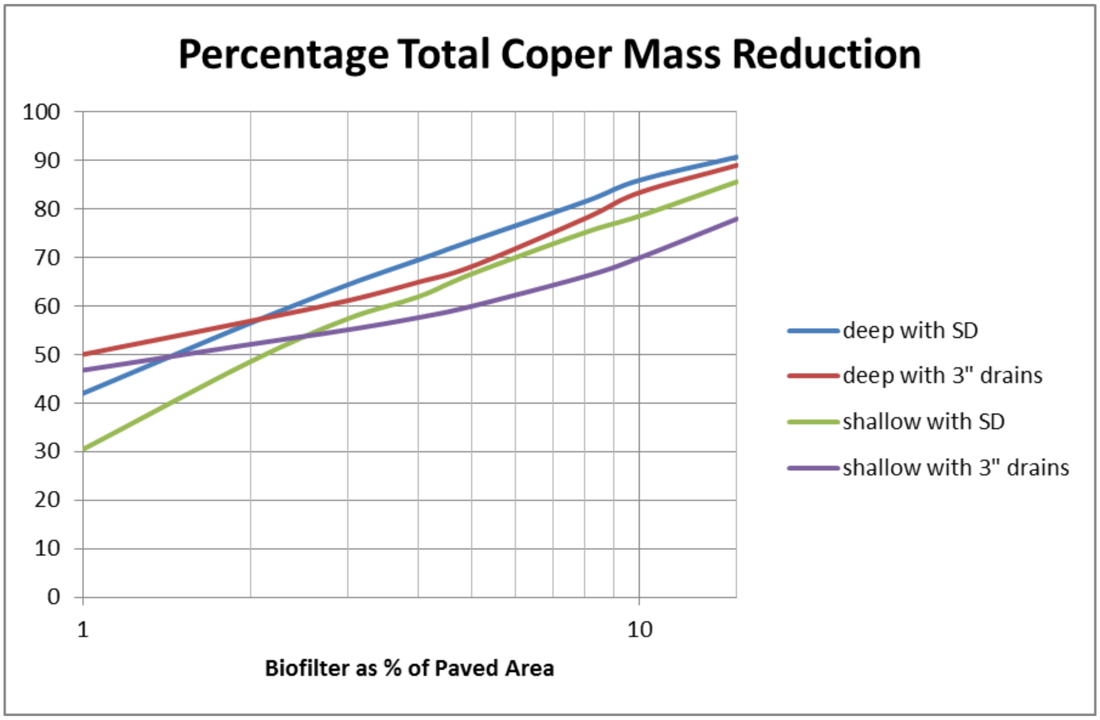


Figure 3-5: Copper Reduction Rates

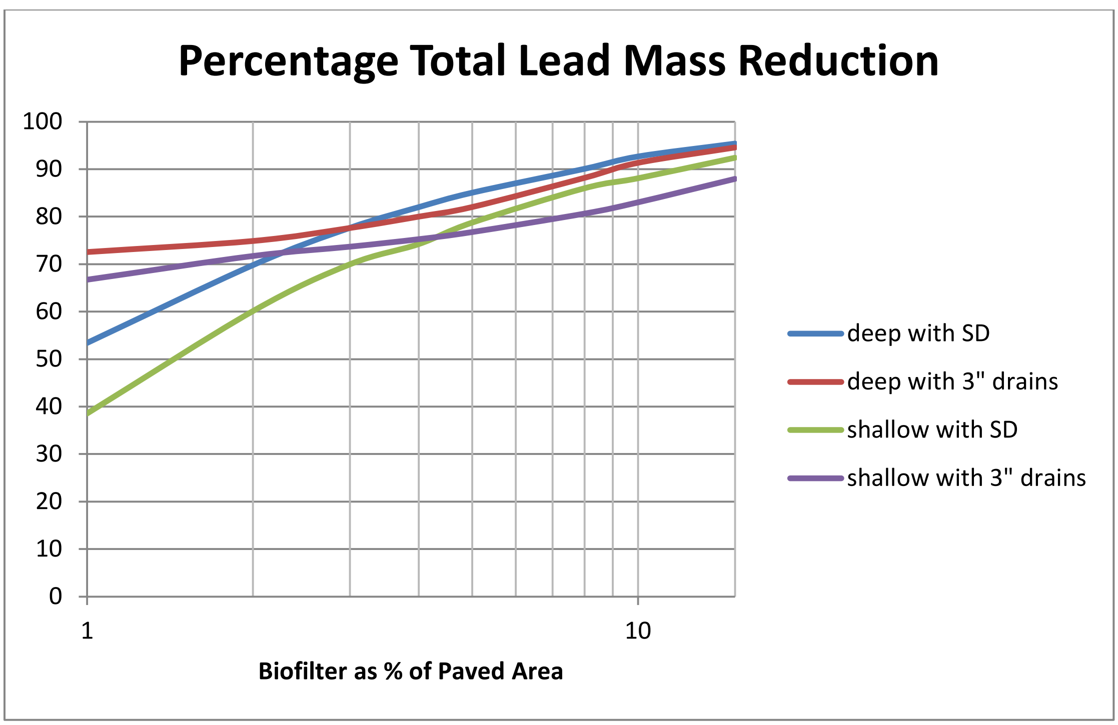


Figure 3-6: Lead Reduction Rates

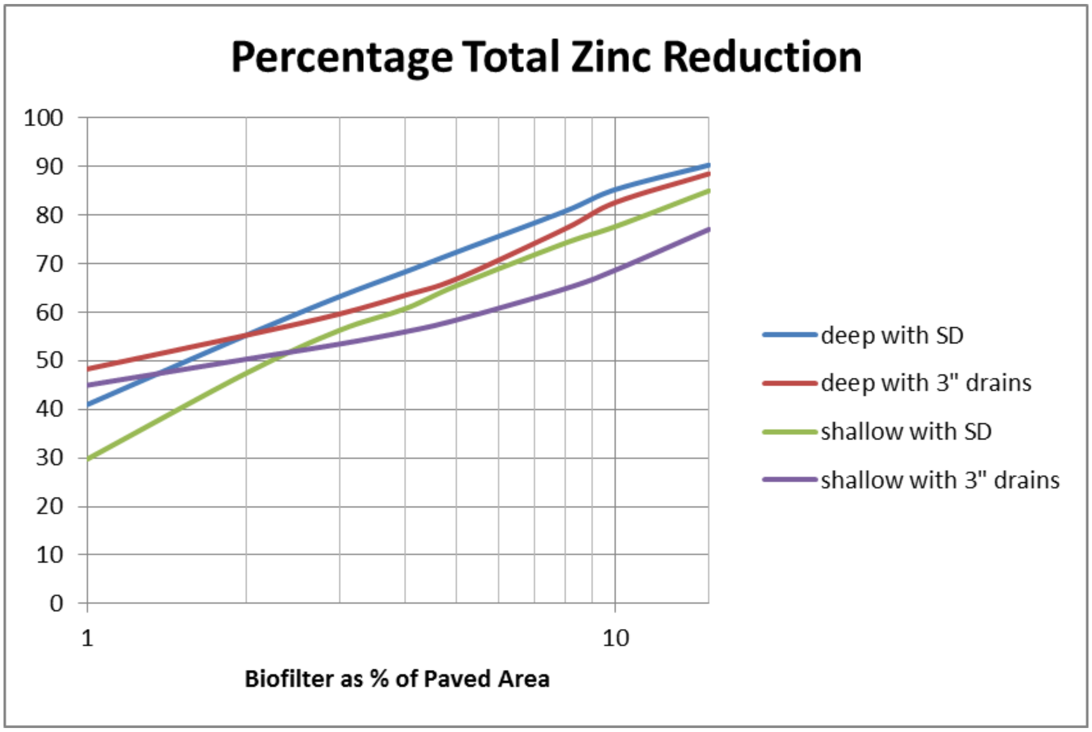


Figure 3-7: Zinc Removal Rates

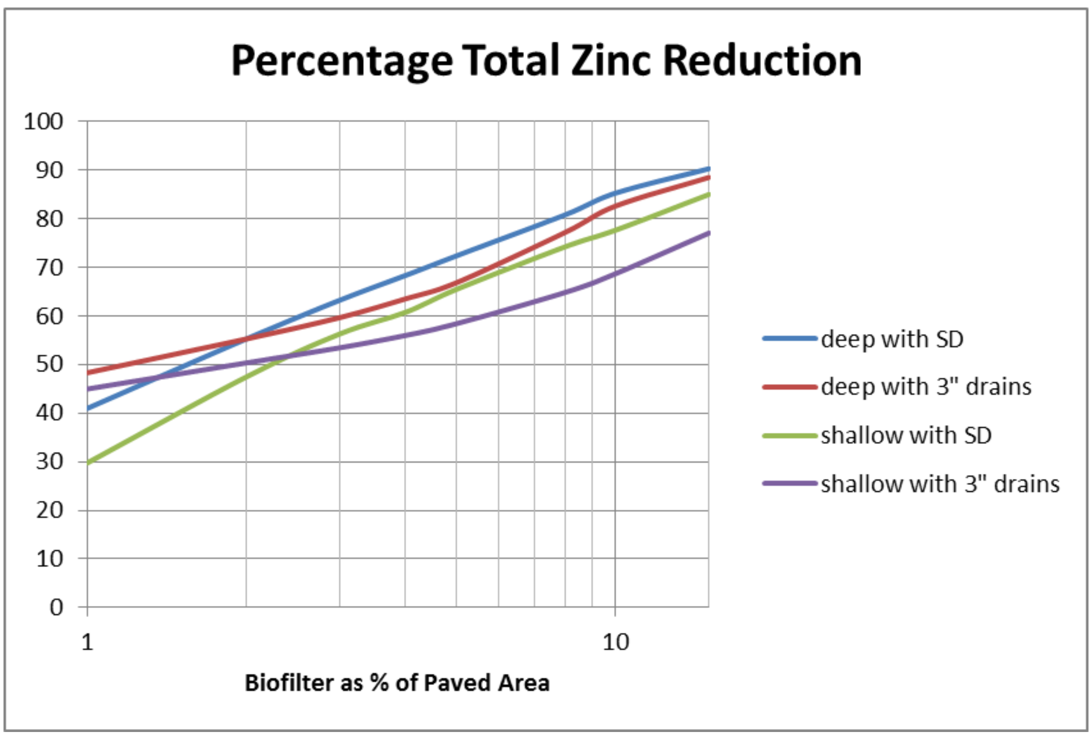


Figure 3-8: Lead Removal Rates

Removal of Filterable Heavy Metals

The removal of small-sized pollutants (colloidal and other filterable forms, generally <1 µm in size, e.g., filterable heavy metals, nitrates, many pesticides, etc.) typically has not been the focus of stormwater runoff treatment, except where TMDLs or known receiving water stressors were a regulatory focus. Clark and Pitt (2012) state that many chemical properties are inter-related, i.e., solubility is related to surface and internal charge distributions. Therefore, prediction models for treatability have focused on a generic surface interaction between the pollutant and the removal media, without separating the reaction type. This focus on an unnamed interaction also acknowledges that adsorption and ion-exchange are gradations of the same process, e.g., a charge interaction between the pollutant and the media.

The following tables summarize the expected influent total, filtered, and particulate-bound concentrations of copper, lead, and zinc for the pilot test locations associated with this project. The previously shown production functions for copper and zinc are very similar because their particulate-bound fractions are similar. However, the lead production function shows greater removals for the same sized facilities because much more of the lead is bound to particulates, which is more effectively removed in the biofilters.

Table 3-5: Expected Influent Total, Filtered, and Particulate-Bound Concentrations

total Cu (µg/L)	particulate Cu (µg/L)	filtered Cu (µg/L)	% of total Cu as filtered Cu
116	69.8	46.6	40.1

total Pb (µg/L)	particulate Pb (µg/L)	filtered Pb (µg/L)	% of total Pb as filtered Pb
24.6	23.0	1.7	6.7

total Zn (µg/L)	particulate Zn (µg/L)	filtered Zn (µg/L)	% of total Zn as filtered Zn
688	392	296	43.0

Treatment of the filtered forms of these metals depends on the characteristics of the filtered material, the residence times in the media, and the media selected. As noted above, the filtered metals are not all in ionic ("dissolved" forms), but can also be colloidal, or complexes, which have different removal mechanisms in biofilters. As an example, higher charged ions are more effectively removed than lower charged (or neutral) ions with ion-exchange processes. During her research, Morquecho (2005) conducted sequential extraction tests of a number of stormwater samples from different source areas to identify the fraction of the metals that were ionic or colloidal bound, as shown in the following table. Both zinc and lead are mostly bound and likely

more difficult to remove by ion exchange, while most of the copper in stormwater may be removed in ionic forms.

Table 3-6: Fraction of Colliodal and Ionic Bound Metals

	Average % of filtered metal in ionic forms	Average % of filtered metals bound as colloids or complexes
Zinc	15	85
Copper	70	30
Lead	12	88

Source: Morquecho 2005

Ogburn (2013) further studied the speciation of stormwater heavy metals using Medusa software, and confirmed through controlled laboratory tests of leaching of different materials. The following list some of the most predominant species of zinc, copper, and lead expected in stormwater:

$Zn_3(PO_4)_2{:}4H_2O(c)$
Zn^{2+}
$Zn(CO_3)_2^{2-}$
$Zn_5(OH)_6(CO_3)_2(c)$

$CuH_2PO_4^{+}$
$CuHPO_4$
$CuH_2(PO_4)_2^{2-}$
Cu^{2+}
$CuO(cr)$

$PbHPO_4(c)$
$Pb_3(PO_4)_2(c)$
Pb^{2+}
$PbSO_4$
$PbCO_3$

These show a range of ionic charge, from -2 to +2, including neutral and complexed forms. Therefore, removal by chemical active treatment media will likely vary depending on the mixture of species actually present in the stormwater being treated (which may vary for different events at the same location). Therefore, combinations of treatment mechanisms are usually the most effective considering the variable stormwater characteristics and treatment objectives.

Ogburn (2013) summarized that in physisorption reactions, the electrical bonds between the contaminants and the media are reversible and weak. On the other hand, during chemisorption and precipitation reactions, stronger bonds are formed and the pollutant retention is permanent if the solution pH and dissolved oxygen level do not change significantly (Evangelou, 1998; Watts,

1998; Clark and Pitt, 2012). Sorption and ion exchange remove pollutants through electrostatic interactions between the media and contaminants (Clark and Pitt, 2012).

Valence charge of a metal and its complexation, among other contaminant properties, influence the choice of stormwater treatment technology (Clark and Pitt, 2012). Strongly charged, small molecules can be removed effectively by zeolites (Clark and Pitt, 2012). Zeolites are not effective in the removal of compounds of zero valence and compounds with large size (Clark and Pitt, 2012). Peat, compost, and soils remove pollutants by chemisorption that is generally irreversible (Watts, 1998; Evangelou, 1998). Peat can be used as a filtration media for treatment of heavy metals and likely their complexes (Clark and Pitt, 2012 and 1999). Peat's effectiveness is due to the wide range of binding sites (carboxylic acid, etc.) present in the humic materials and ligands in the peat (Cohen et al., 1991; Sharma and Foster, 1993; Clark and Pitt, 2012). An advantage of peat media is that it can treat many heavy metals during relatively short (10 minutes) contact times (Pitt and Clark, 2010; Clark and Pitt, 2012). The peat's drawbacks (especially for Sphagnum peat) include the leaching of colored humic and fulvic acids and the release of hydronium ions (H_3O^+) in exchange for metals which can lower the pH of the treated water by as much as 1 to 2 pH units and increase the solubility of the metals that were associated with stormwater runoff solids or media (Clark and Pitt, 2012 and 1999).

An effective treatment train includes sedimentation and/or physical filtration (as provided in biofilters) which capture metals that are bound to particles. These metals can be associated with very small particles; therefore, the efficiency of physical filtration to remove metals will depend on size of associated particulates. Treatment technologies for metals associated with dissolved fraction include chemical methods associated with the selected treatment media. To remove dissolved metals from stormwater, peat moss, mixtures of peat moss and sand, zeolite, and compost can be used, especially with long contact times (such as the several hours expected for these project sites). These metals can form soluble complexes with different inorganic and organic ligands. The complex valence can range from -2 to +2. Organic and inorganic complexes may be treated by chemically active filtration through compost, peat, and soil. Also, granular activated carbon (GAC) can be used to remove complexes with organic matter, if peat/sand mixtures are not expected to be sufficient.

Table 3-7: Removal Mechanisms for Lead, Copper, and Zinc is a summary of the treatment processes from Clark and Pitt (2012).

Table 3-7: Removal Mechanisms for Lead, Copper, and Zinc

	Metals	
Lead	Ion-exchange Chemically-active media filtration	• Lead attaches strongly to solids. Substantial removal by sedimentation and/or physical filtration of solids to which lead is attached. • Lead < 0.45 µm may be ionic and could be removed using ion-exchange with zeolites, but filtered, ionic lead is usually at very low concentrations and it would be unusual to require treatment. • Lead complexes with hydroxides and chlorides to a certain extent. Removed in media with variety of binding sites (peat, compost, soil).
Copper and Zinc	Chemically-active filtration	• These metals can attach to very small particles, with attachments being a function of the particulate organic content, pH, and oxidation-reduction conditions (filterable fractions vary from 25 to 75+%). Physical filtration may be limited depending on size association of the pollutants. • These metals complex with a variety of organic and inorganic ligands to create soluble complexes of varying valence charges (-2 to +2). Small amount of ionic species (metal as +2 ion only) reduces ion-exchange effectiveness. • Complexes require variety types of sorption/exchange sites. Organic complexes may be removed by GAC. Peat, compost, and soil will remove most inorganic and organic complexes. • Concern about background contamination of media with metals.

The following figures are performance plots associated with a range of biofilter media that were developed and tested for a southern California industrial facility having a broad range of rather restrictive numeric effluent limits (Pitt and Clark, 2010). The red dashed line indicates the regulatory discharge limits. Most of the effluent samples for lead shown in Figure 3-9: Performance Plots for Copper from Column Tests were below the detection limit due to the high fraction of particulate-bound lead.

The typical flow rates for all of these media options were at least 8 in/hr. Slower flows and longer contact times could be provided using restrictive underdrains (such as the SmartDrain™).

The selected media from this research (the R: Rhyolite sand; SMZ: surface modified zeolite; and GAC: granular activated carbon) has been used at several large biofilters for the Boeing Co. in Southern California and Puget Sound with success for a broad range of contaminants.

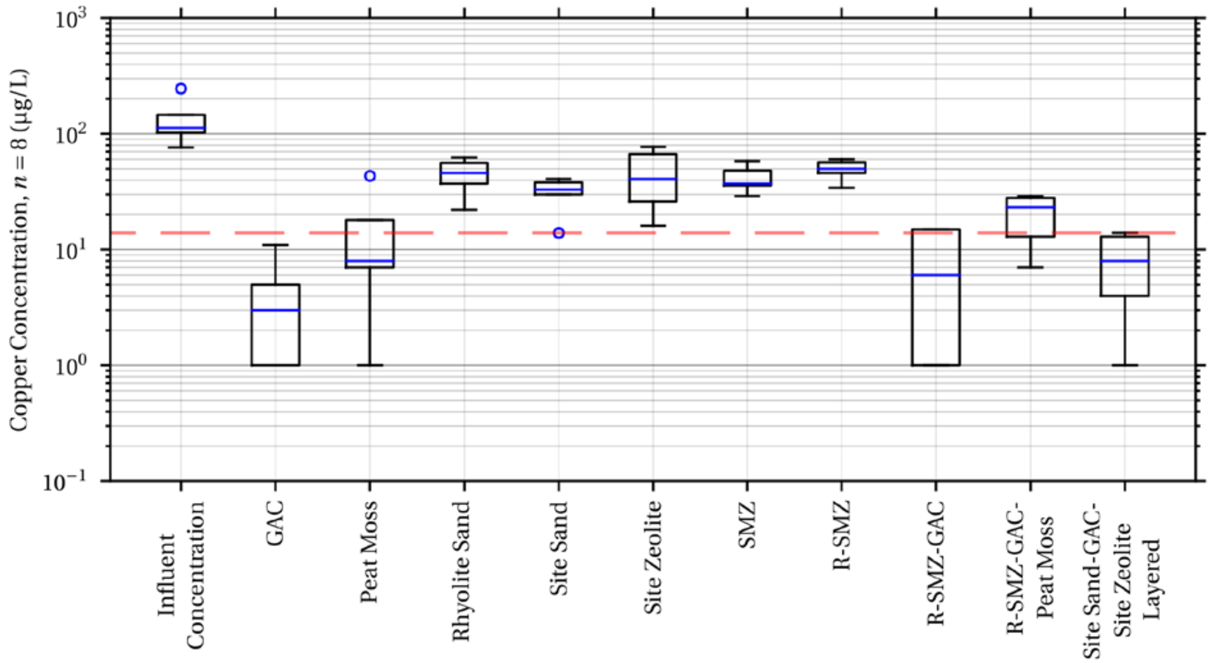


Figure 3-9: Performance Plots for Copper from Column Tests

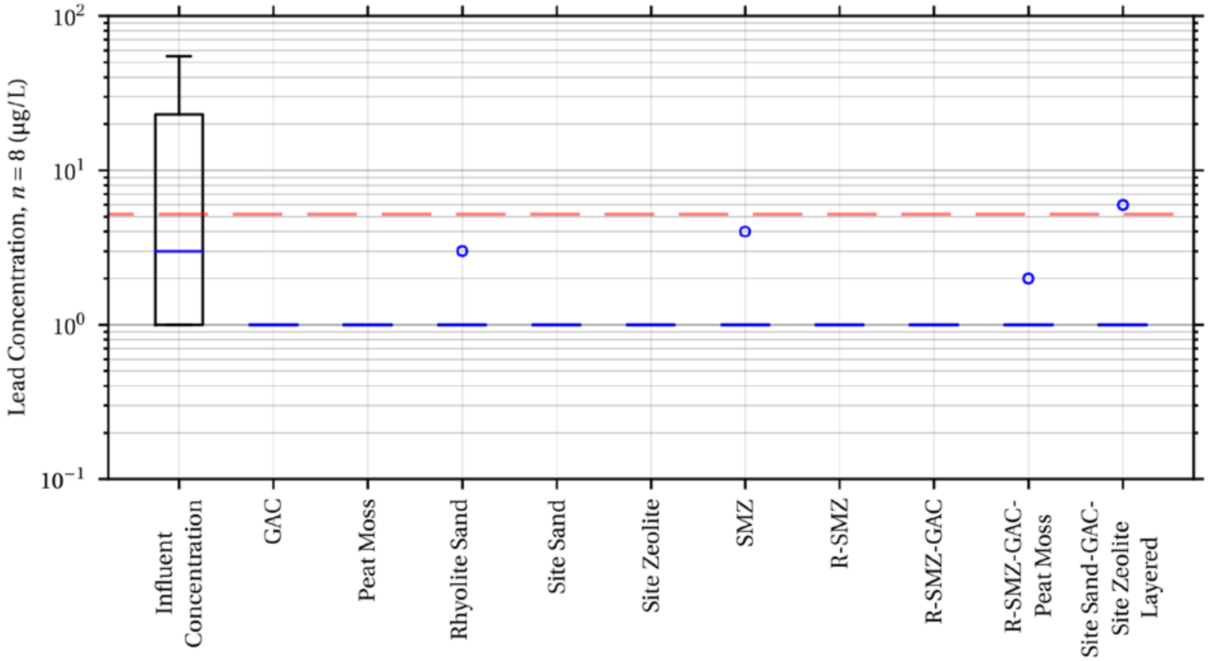


Figure 3-10: Performance Plots for Lead from Column Tests

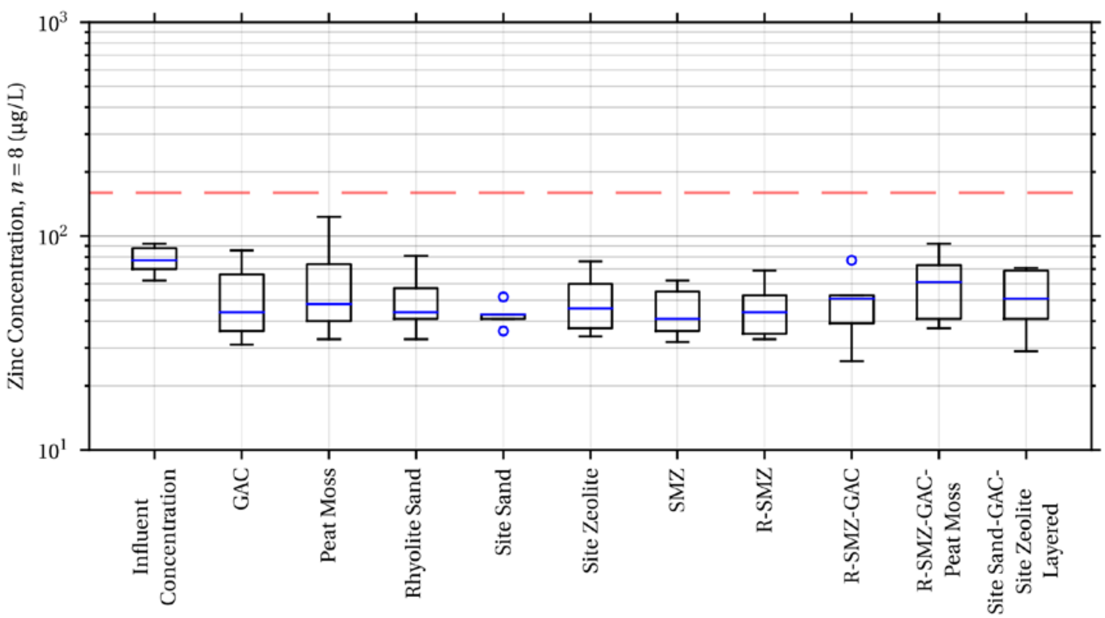


Figure 3-11: Performance Plots for Zinc From Column Tests

Of these three metals of concern for the NBSD sites, copper and zinc are more challenging for removal than lead. Most of the lead is associated with particulates and is likely to be reduced to

levels well below site objectives with just the particulate-bound material removals. When focusing on just these two metals, the following biofilter media options are expected to provide low effluent concentrations:

- Peat moss (mixed with sand) (likely the least costly)
- GAC (mixed with sand)
- R-SMZ-GAC mixture (the most costly, but most effective for many other stormwater constituents also)

A sand/peat/GAC mixture is also effective and has been used in large-scale MCTT (Multi-Chambered Treatment Train) installations at critical source areas when focusing on metals and organic toxicants (Pitt et al., 1999). Existing site soils and compost are not listed on this preferred list due to typical problems with these components. Site soils are also highly variable and usually contain adverse amounts of fines (clays and silts) which are subject to compaction and high rates of failure. Compost must be from a controlled and verified source otherwise it can be extremely variable and is known to be a major source of phosphorus (and possibly other constituents) in the treated effluent. Recent studies have shown that a proprietary media that consists of high grade compost and industrial byproducts has been extremely effective at reducing loads of zinc, copper, and lead as well as phosphorus (Gleason, 2013).

3.4 Description of LID Pilot Project Concept Designs

This section includes detailed descriptions of the BMP design for each location. They include a description of the technology used and the design approach, a concept plan, a preliminary opinion of cost, and a cross section of the design. The projected water quality benefits were evaluated for each project location using the WinSLAMM model. The results are summarized for each pilot project location and further discussed in the section on modeling. The four (4) LID Pilot Project Sites are as follows:

- *LID Pilot Project Site 1: Bioswale and Bioretention Cell.* These are a bioswale and biocell that will be retrofitted into the existing parking area at the northwest corner of the parking area that runs along the railroad tracks (Location 5 – See Figure 3-2). This will require the relocation of the existing sidewalk away from the paved area to closer to the retaining wall to provide the best location for the stormwater controls. This project will require less than 1,000 square feet of construction.
- *LID Pilot Project Site 2: Bioretention Cell.* This project is to retrofit an inlet in the parking area in front of the Naval Exchange (Location 14 – See Figure 3-2) with a bioretention cell that will require the removal of four (4) parking spaces. This project will require less than 1,000 square feet of construction.
- *LID Pilot Project Site 3: Bioswale.* A bioswale can be retrofitted adjacent to the access road at the top of the hill directly to the north of the Navy Federal Project (Location 23 – See Figure 3-2). This swale will require curb cuts to collect the water from the access road. This project will require less than 1,000 square feet of construction.

- *LID Pilot Project Site 4: Bioretention Cell.* A bioretention cell will be retrofitted in the parking area near Building 268 as shown in the northeast corner of Figure 3-2. A concrete curb will be installed in the parking area to direct runoff to the cell. Four (4) parking spaces will need to be relocated. This project will require less than 1,000 square feet of construction.

3.4.1 LID Pilot Project Site 1: Bioswale and Bioretention Cell

This project is a bioswale and biocell that will be retrofitted into the existing parking area at the northwest corner of the parking area that runs along the railroad tracks. The project at this location will show how an individual cell can be constructed to fit into a narrow strip configuration. Figure 3-12: Schematic of LID Pilot Project Site 1 Location is an aerial view of the potential location. Figure 3-13: LID Pilot Project Site 1 Concept is of the proposed bioswale and cell. The swale and cell will be shallow, (less than two (2) feet) because of the depth of the existing storm drain and inlet. The strip will be approximately four (4) feet in width and 40 feet long. The swale is in a small, constricted area. It can be constructed with deep curbs around the edges to contain the media and support the pavement. A portion of the sidewalk will have to be relocated away from the pavement towards the retaining wall to accommodate the construction. Figure 3-14: Navy Yard Bioretention strip is a picture of a similar existing facility that has been in place for over 15 years. The cell will have a surface area of 1,600 square feet and depth of two (2) feet. A preliminary concept plan is shown in Figure 3-15: LID Pilot Project Site 1 Plan View. Figure 3-16: LID Pilot Project Site 1 Cross Section shows a preliminary schematic of the cell and adjacent pavement. The figures also include a preliminary location of monitoring equipment. This will be further discussed in the monitoring section.

The drainage area is approximately 1.15 acres. The resultant drainage area ratio is 30 to 1. The effectiveness of this cell, based on the initial results of the water quality study, indicate a long-term average effluent concentration of zinc of about 0.4 mg/L, copper of 0.07 mg/L, and lead of 0.8 mg/L. Table 3-8: LID Pilot Project Site 1 Projected Water Quality Benefits summarizes the calculated performance of the proposed biofilter at this location for the 62 year rain record.

The cost to construct this system is estimated at $37,000. A detailed description of the cost is included in Appendix B: Preliminary Opinion of Cost. Maintenance of the system will be minimal. The maintenance will consist of removing sediment and debris from the areas of the curb cuts within the cell, trimming and replacing any dead plant materials in the cell, and removing any debris from the inlet. This should occur twice a year.

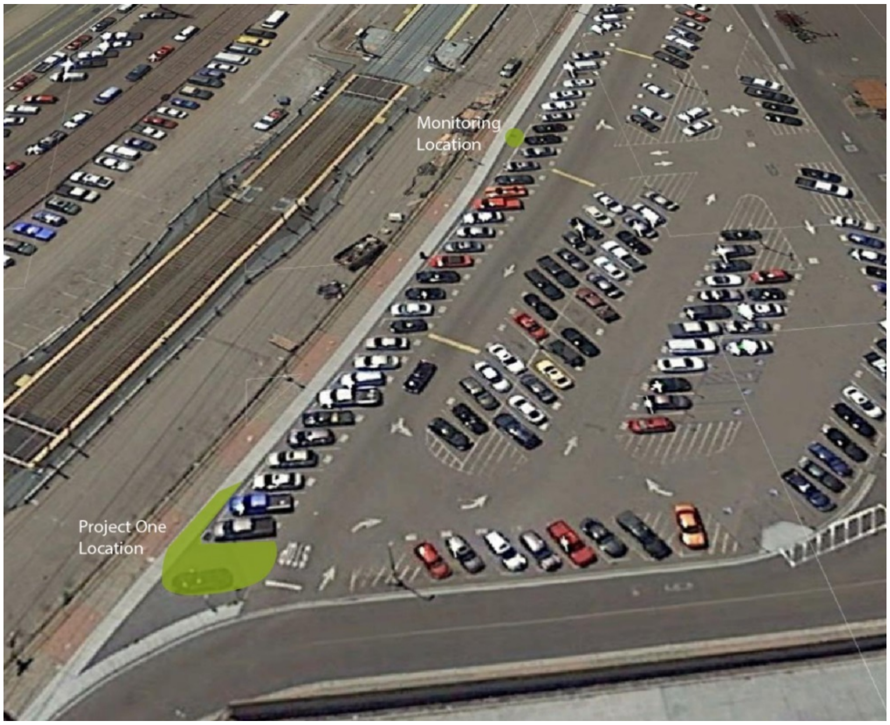


Figure 3-12: Schematic of LID Pilot Project Site 1 Location

Figure 3-13: LID Pilot Project Site 1 Concept

Figure 3-14: Navy Yard Bioretention

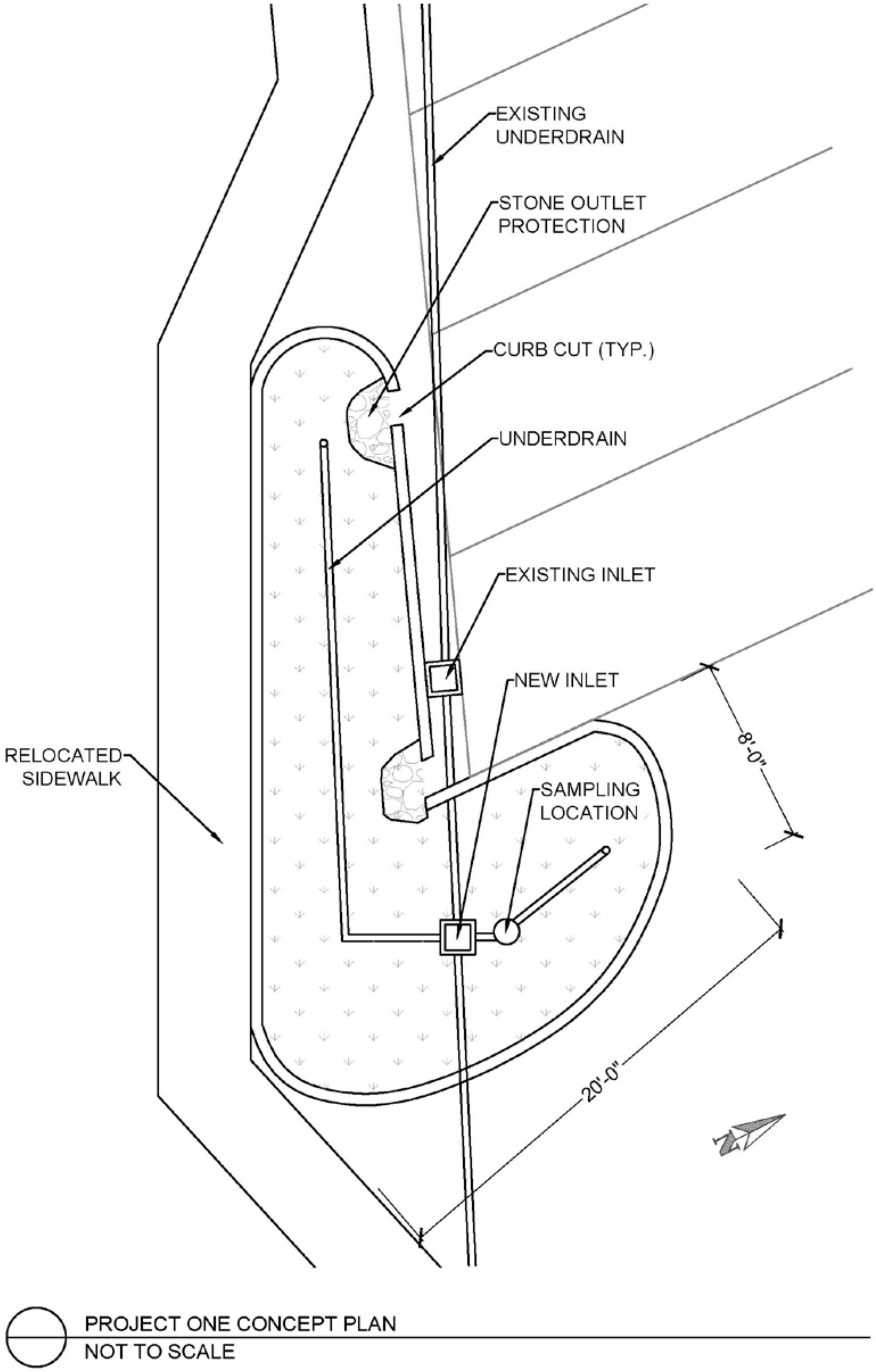


Figure 3-15: LID Pilot Project Site 1 Plan View

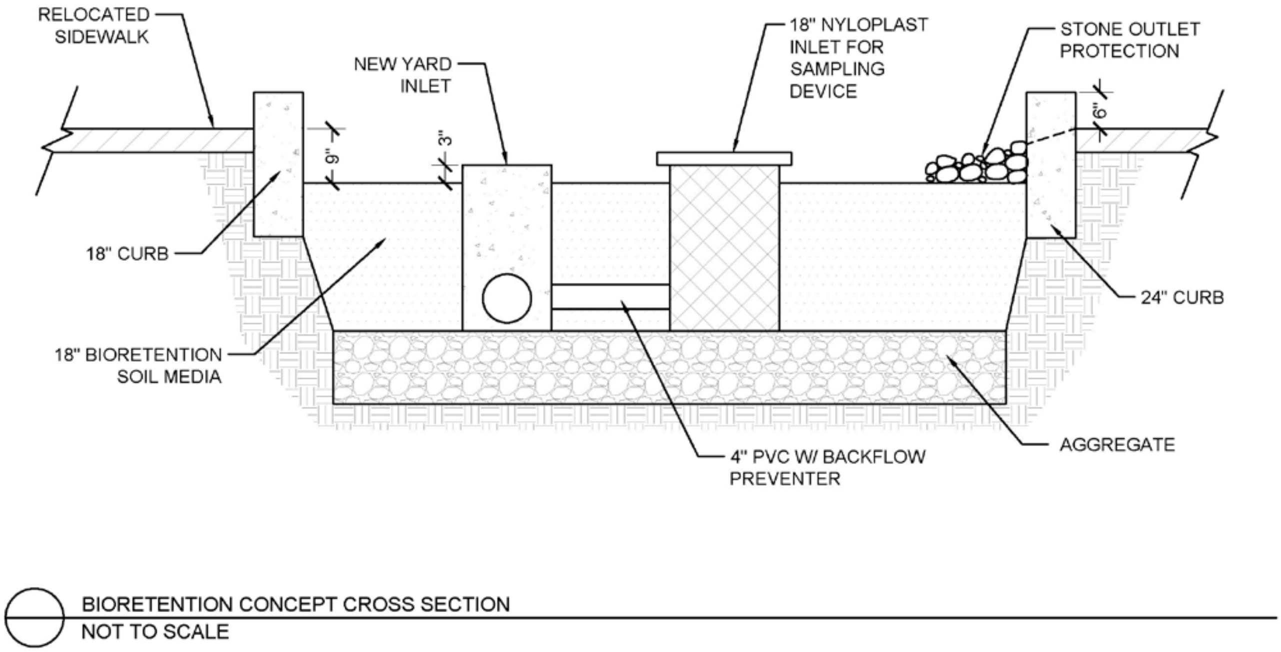


Figure 3-16: LID Pilot Project Site 1 Cross Section

Table 3-8: LID Pilot Project Site 1 Projected Water Quality Benefits

Project Site	1
Biofilter Footprint (ft^2)	1,500
Drainage Area (ac)	1.15
Biofilter Size (% of area)	2.99
% of Runoff Reduction	19.1
Ratio of Runoff to Rain Volume (Rv)	0.56
% Particulate Solids Mass Reduction	77.7
Particulate Solids Effluent Concentration (mg/L)	21
Total Cu Effluent Concentration (ug/L)	65.9
% Total Cu Mass Reduction	54.3
Total Pb Effluent Concentration (ug/L)	8.0
% Total Pb Mass Reduction	73.7

Total Zn Effluent Concentration (ug/L)	404
% Total Zn Mass Reduction	52.6
Median Particle Size (um)	2.26
Maximum Stage (ft)	4.58
Maximum Surface Ponding (hrs)	6.1
Total Inflow (ft^3)	1,771,000
Volume Infiltration (ft^3)	381,432
Underdrain Discharge (ft^3)	1,367,870
Evapotranspiration (ET) Water Losses (ft^3)	38,644
Surface Discharge (ft^3)	9,471
Surface Ponding Events(>72 hrs)	0
Runoff Producing Events (out of 2,348 total events and %)	1,068 (46%)

3.4.2 LID Pilot Project Site 2: Bioretention Cell in Navy Exchange Parking Area

This project will install a bioretention cell around an existing inlet in the parking area. The cell construction will require four (4) parking spaces. This site is appropriate because it is the only location with sufficient drainage area and there are no large-scale construction requirements for installation or major disruptions to traffic during construction. The construction will take approximately a week and will only temporarily disturb a small portion of the parking lot. It can

also be used as an outreach tool as it is centrally located and signage can easily be installed. The maintenance required will also be minimal. Figure 3-17: LID Pilot Project Site 2 Location shows the location of the cell. The existing inlet would have to be modified by lowering the top approximately one (1) foot. A curb, with curb cuts to allow water to flow into the cell, will be constructed. The media depth will be three (3) feet in order to achieve sufficient storage. The area can be planted and the surface finished with mulch or decorative stones. Figure 3-18: LID Pilot Project Site 2 Concept Plan is a schematic of the concept plan view and Figure 3-19: LID Pilot Project Site 2 Cross Section is a concept cross section.

The drainage area is approximately 0.50 acres. The resultant drainage area ratio is 27 to 1. The effectiveness of this cell, based on the initial results of the water quality study, indicates a long-term average concentration of zinc of 0.4 mg/L and copper of 0.07 mg/L. Table 3-9: LID Pilot Project Site 2 Projected Water Quality Benefits summarizes the calculated performance of the proposed biofilter at this location for the 62 year rain record. The preliminary opinion of cost is \$40,000. The maintenance for this facility will be similar to LID Pilot Project Site 1. The decommissioning of the site, if desired, would also be relatively straightforward. The media and curb could be removed and the inlet restored to the original elevation. A new compacted subbase and asphalt can be installed at the original elevation.

Table 3-9: LID Pilot Project Site 2 Projected Water Quality Benefits

Project Site	2
Biofilter Footprint (ft^2)	800
Drainage Area (ac)	0.5
Biofilter Size (% of area)	3.67
% of Runoff Reduction	22.8
Ratio of Runoff to Rain Volume (Rv)	0.54
% Particulate Solids Mass Reduction	79.1
Particulate Solids Effluent Concentration (mg/L)	20.6
Total Cu Effluent Concentration (ug/L)	65.5
% Total Cu Mass Reduction	56.6
Total Pb Effluent Concentration (ug/L)	7.9
% Total Pb Mass Reduction	75.3

Total Zn Effluent Concentration (ug/L)	402
% Total Zn Mass Reduction	54.9
Median Particle Size (um)	2.22
Maximum Stage (ft)	4.54
Maximum Surface Ponding (hrs)	4.8
Total Inflow (ft^3)	770,132
Volume Infiltration (ft^3)	196,683
Underdrain Discharge (ft^3)	566,002
Evapotranspiration (ET) Water Losses (ft^3)	20,019
Surface Discharge (ft^3)	1,266
Surface Ponding Events (>72 hrs)	0
Runoff Producing Events (out of 2,348 total events and %)	980 (42%)

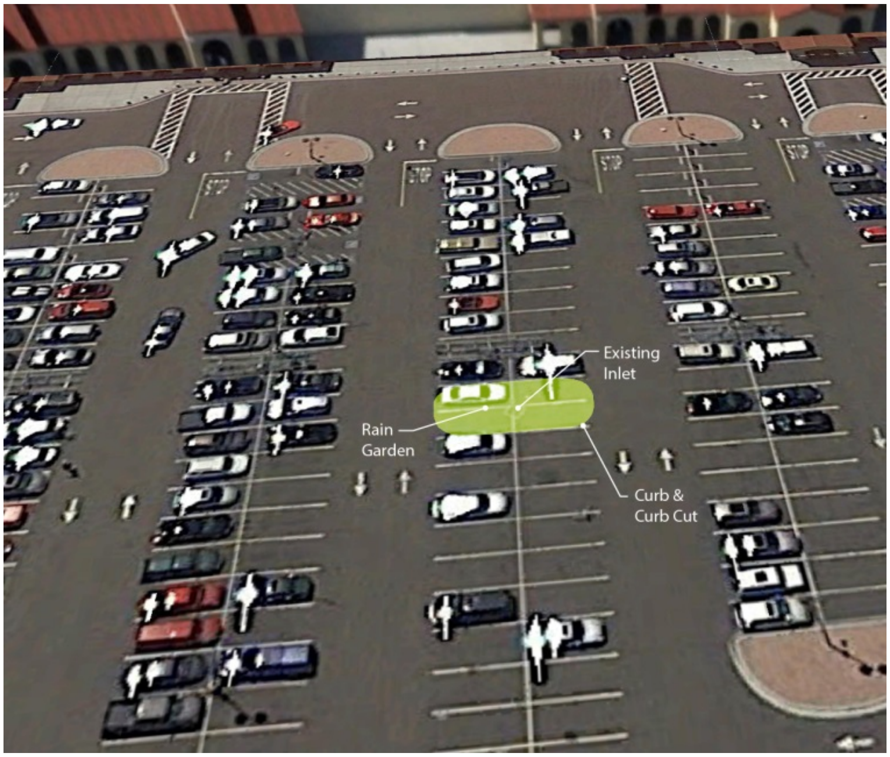


Figure 3-17: LID Pilot Project Site 2 Location

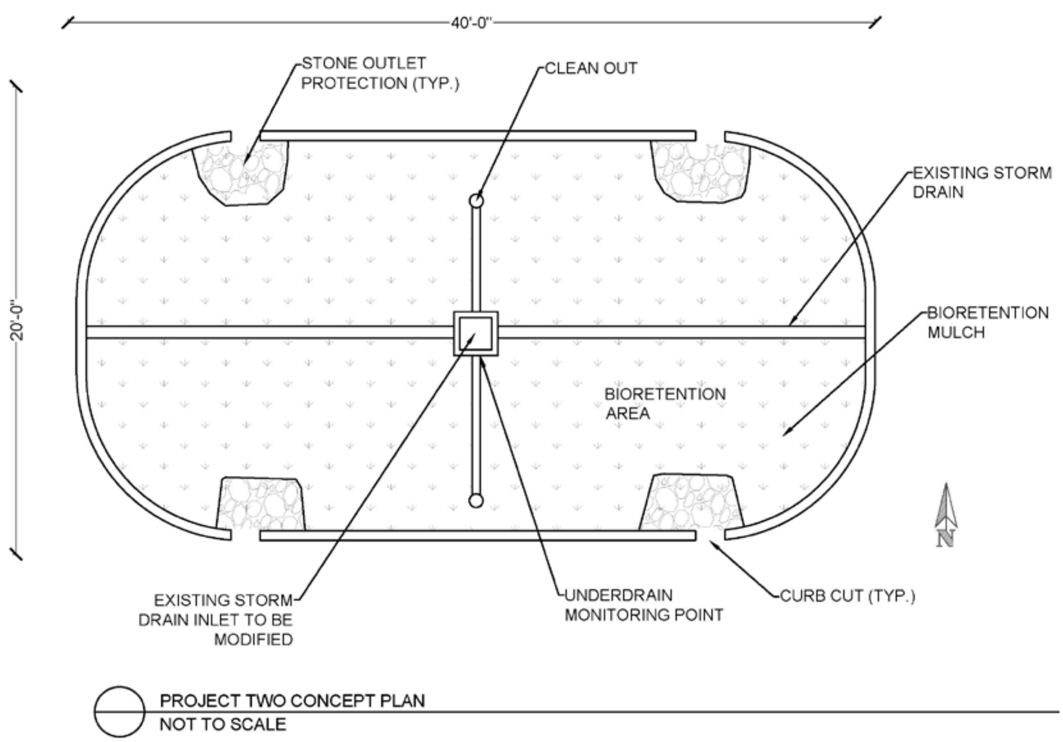


Figure 3-18: LID Pilot Project Site 2 Concept Plan

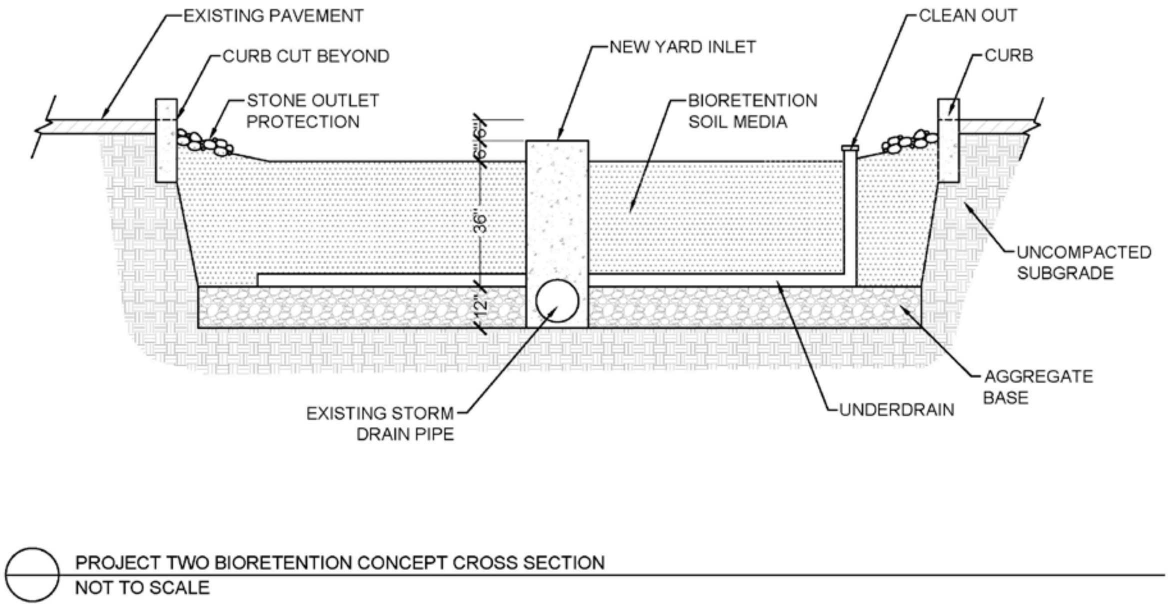


Figure 3-19: LID Pilot Project Site 2 Cross Section

3.4.3 LID Pilot Project Site 3: Bioswale along Colton Avenue

This project will be to construct a bioswale along the top of the hill at Colton Avenue and discharge to the existing storm drain system. This is shown in Figure 3-20: LID Pilot Project Sites 3 and 4 Location. The area at the top of the hill is relatively narrow and the swale will be only four (4) feet wide but sixty (60) feet long to obtain sufficient surface area. Curb cuts will be used to direct water from the street to the swale. A yard inlet will be placed at the end of the swale. This will then connect with a storm drain pipe to the existing manhole. Figure 3-21: LID Pilot Project Site 3 Concept Design Schematic is a schematic of the design. Figure 3-22: LID Pilot Project Site 3 Concept Plan and Figure 3-23: LID Pilot Project Site 3 Cross Section show preliminary details of the design.

Figure 3-20: LID Pilot Project Sites 3 and 4 Location

Figure 3-21: LID Pilot Project Site 3 Concept Design Schematic

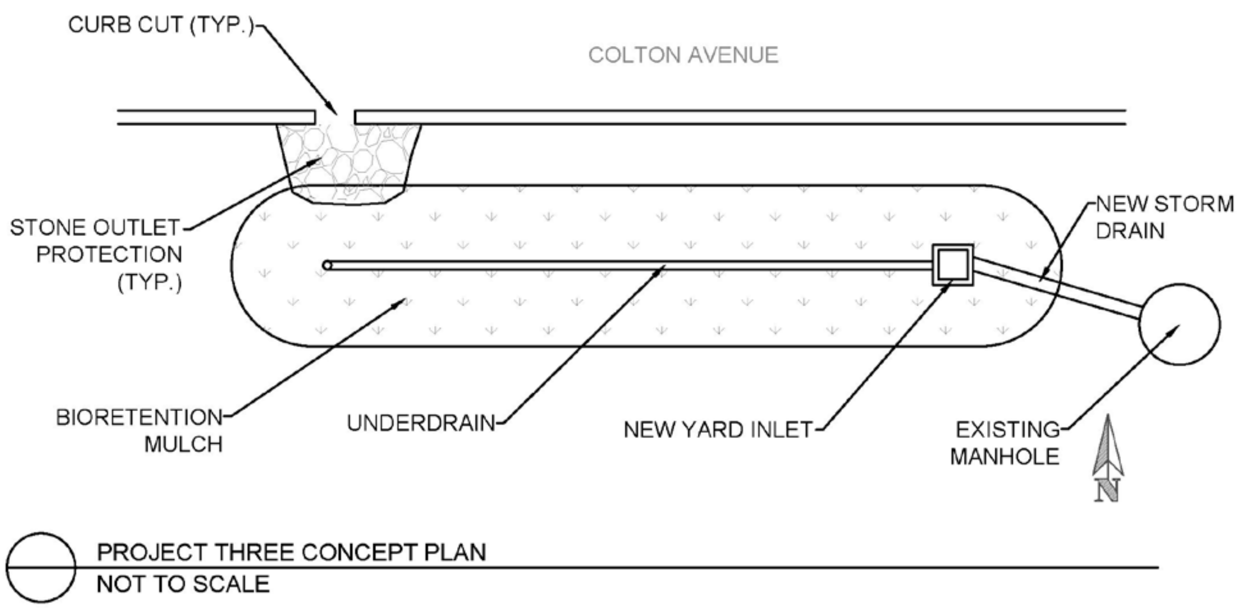


Figure 3-22: LID Pilot Project Site 3 Concept Plan

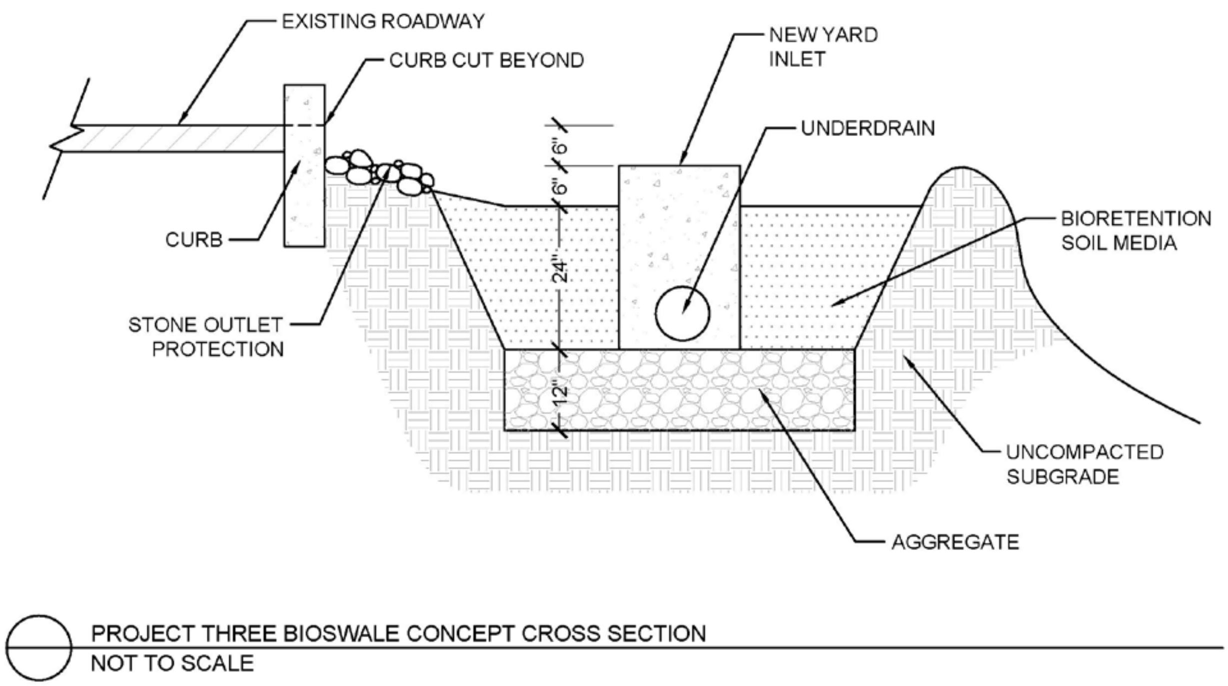


Figure 3-23: LID Pilot Project Site 3 Cross Section

The depth of the media will be approximately 2.5 feet. The drainage area is approximately 0.85 acres. The resultant drainage area ratio is 150 to 1. The effectiveness of this cell, based on the initial results of the water quality study, indicates a long-term average concentration of zinc of 0.46 mg/L and copper of 0.08 mg/L.

Table 3-10: LID Pilot Project Site 3 Projected Water Quality Benefits summarizes the calculated performance of the proposed biofilter at this location for the 62 year rain record. Additional investigation should also be conducted to verify the drainage area and to calculate the length of the curb cut openings so that a more accurate depiction of the inflow conditions can be determined. The cost for this system is estimated at $33,000. The maintenance is similar to the other cells.

Table 3-10: LID Pilot Project Site 3 Projected Water Quality Benefits

Project Site	3	Total Zn Effluent Concentration (ug/L)	460
Biofilter Footprint (ft^2)	240	% Total Zn Mass Reduction	37
Drainage Area (ac)	0.85	Median Particle Size (um)	6.04
Biofilter Size (% of area)	0.65	Maximum Stage (ft)	4.59
% of Runoff Reduction	5.7	Maximum Surface Ponding (hrs)	30.3
Ratio of Runoff to Rain Volume (Rv)	0.66	Total Inflow (ft^3)	1,309,000
% Particulate Solids Mass Reduction	60.6	Volume Infiltration (ft^3)	78,667
Particulate Solids Effluent Concentration (mg/L)	31.7	Underdrain Discharge (ft^3)	923,999
Total Cu Effluent Concentration (ug/L)	75.8	Evapotranspiration (ET) Water Losses (ft^3)	7,688
% Total Cu Mass Reduction	38.6	Surface Discharge (ft^3)	302,813
Total Pb Effluent Concentration (ug/L)	11.3	Surface Ponding Events (>72 hrs)	0
% Total Pb Mass Reduction	56.9	Runoff Producing Events (out of 2,348 total events and %)	1,575 (67%)

3.4.4 LID Pilot Project Site 4: Bioretention Cell.

This project will be to construct a bioretention cell that ties into the existing storm drain system at the southeast corner of the parking area near building 268. Runoff would be directed from the parking lot by placing a curb along the lower portion of the lot. This is shown in Figure 3-20: LID Pilot Project Sites 3 and 4 Location Colton Avenue. Details are shown in Figure 3-24: LID Pilot Project Site 4 Concept Plan and Figure 3-25: LID Pilot Project Site 4 Cross Section. An inlet will be constructed to tie into the existing storm drain system that runs along Colton Avenue.

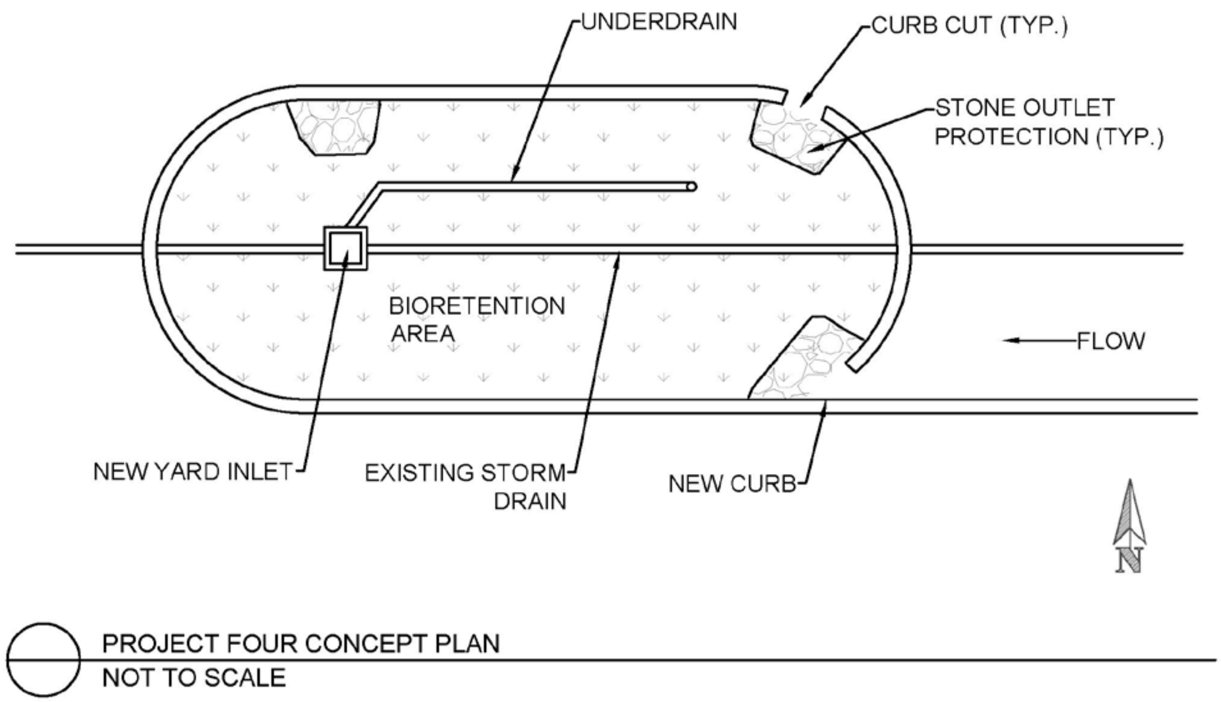


Figure 3-24: LID Pilot Project Site 4 Concept Plan

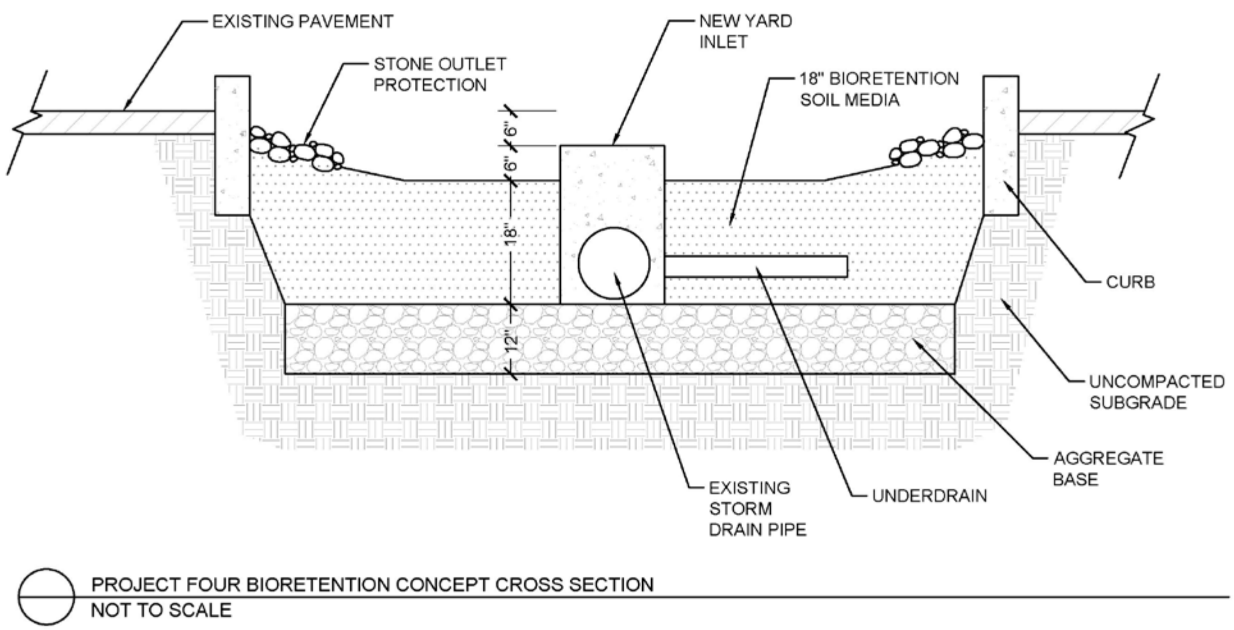


Figure 3-25: LID Pilot Project Site 4 Cross Section

The area of the cell would be approximately 800 square feet and 2.5 feet deep. The drainage area is approximately 0.70 acres. The resultant drainage area ratio is 19 to 1. The effectiveness of this cell, based on the initial results of the water quality study indicates a long-term average concentration of zinc of 0.4 mg/L and copper of 0.06 mg/L. Table 3-11: LID Pilot Project Site 4 Projected Water Quality Benefits summarizes the calculated performance of the proposed biofilter at this location for the 62 year rain record.

Additional investigation should also be conducted to verify the drainage area and to calculate the length of the curb cut openings so that a more accurate depiction of the inflow conditions can be determined. The cost for this system is estimated at $37,000. The maintenance requirements are similar to the other locations.

The construction of the Navy Federal Bank with its LID BMPs can be leveraged as potential LID monitoring sites that would not require any additional construction. Figure 4-3: Navy Federal Monitoring Locations shows potential locations where the outflow from bioretention cells can be monitored. Our evaluation identified two cells that could be included for monitoring as part of the overall LID evaluation study. A summary of the drainage areas from each of the projects is included in Table 3-12: Approximate Drainage Area Sizes. The drainage areas are all relatively close in size, have similar land uses, and are easily accessible. This will facilitate the monitoring effort.

Table 3-11: LID Pilot Project Site 4 Projected Water Quality Benefits

Project Site	4	Total Zn Effluent Concentration (ug/L)	398
Biofilter Footprint (ft^2)	1,600	% Total Zn Mass Reduction	59.4
Drainage Area (ac)	0.7	Median Particle Size (um)	2.21
Biofilter Size (% of area)	5.25	Maximum Stage (ft)	4.37
% of Runoff Reduction	29.9	Maximum Surface Ponding (hrs)	2.7
Ratio of Runoff to Rain Volume (Rv)	0.49	Total Inflow (ft^3)	1,078,000
% Particulate Solids Mass Reduction	81.6	Volume Infiltration (ft^3)	360,553
Particulate Solids Effluent Concentration (mg/L)	19.9	Underdrain Discharge (ft^3)	706,981
Total Cu Effluent Concentration (ug/L)	64.9	Evapotranspiration (ET) Water Losses (ft^3)	37,828
% Total Cu Mass Reduction	60.9	Surface Discharge (ft^3)	0
Total Pb Effluent Concentration (ug/L)	7.7	Surface Ponding Events >72 hrs)	0
% Total Pb Mass Reduction	78.2	Runoff Producing Events (out of 2,348 total events and %)	822 (35%)

Table 3-12: Approximate Drainage Area Sizes

Project	Area (ac.)
LID Pilot Project Site 1: Bioretention Cell and Swale	1.15
LID Pilot Project Site 2: Bioretention Cell	0.50
LID Pilot Project Site 3: Bioretention Swale	0.85
LID Pilot Project Site 4: Bioretention Cell	0.70
LID Pilot Project Site 5: Reference Site	0.73
LID Pilot Project Site 6: Navy Federal Bank Site 1	0.57
LID Pilot Project Site 7: Navy Federal Bank Site 2	0.37

4.0 MONITORING LOCATIONS

Each of the four (4) project locations can be monitored for water quality and flow rates. They can all be monitored in a similar manner as shown in Figure 3-15: LID Pilot Project Site 1 Plan View and Figure 3-16: LID Pilot Project Site 1 Cross Section. There are one or more inflow points to each bioretention area for pretreatment collection of samples and an underdrain or inlet where the outflow sampling can occur. The monitoring equipment can be placed in a small shed or in a monitoring manhole or vault so it is secure. Figure 4-1: Proposed LID Pilot Project Sites and Monitoring Locations shows the potential monitoring locations for the study.

A reference location is also identified in this report. The reference location is a similar parking area that is highly utilized. It can be used for comparison as a paired watershed study with any one of the four (4) project locations. A monitoring location can be placed at the inlet shown in Figure 3-16: LID Pilot Project Site 1 Cross Section. This will greatly enhance and support the monitoring results. The location is shown in Figure 4-1: Proposed LID Pilot Project Sites and Monitoring Locations and Figure 4-2: Reference Monitoring Location.

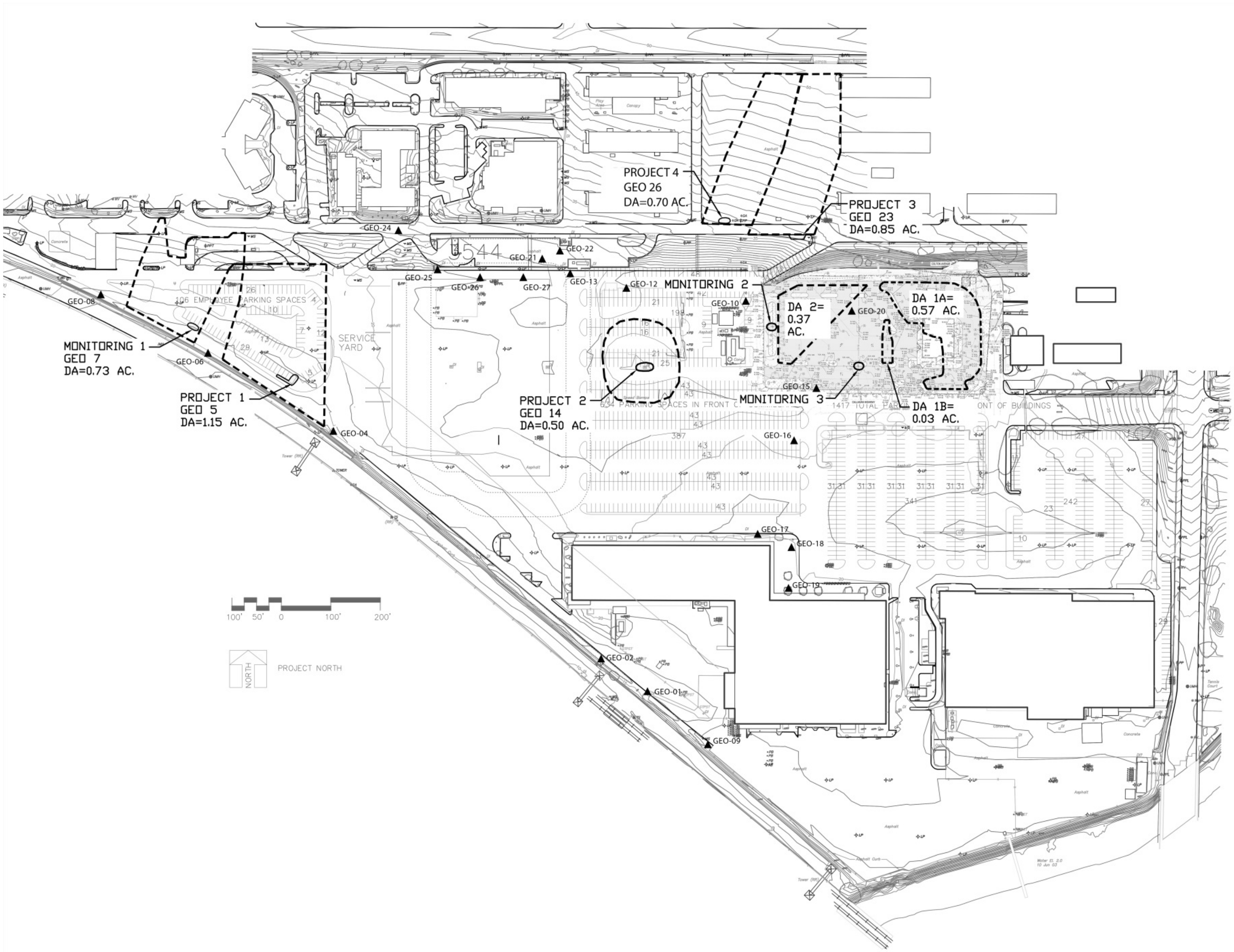


Figure 4-1: Proposed LID Pilot Project Sites and Monitoring Locations

Figure 4-2: Reference Monitoring Location

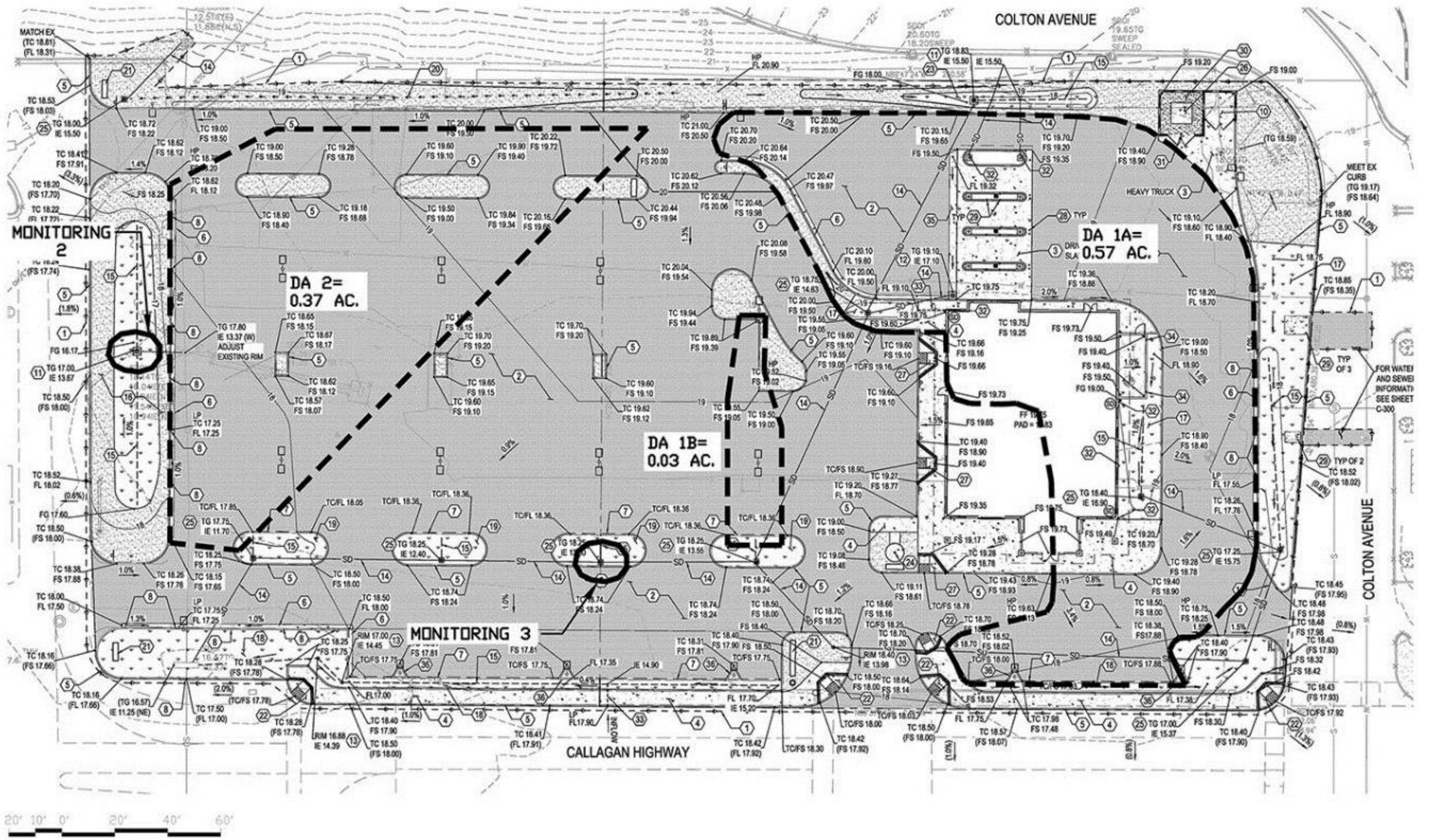


Figure 4-3: Navy Federal Monitoring Locations

The results of the WINSLAMM model for the analysis of copper, lead, and zinc are summarized in Table 4-1: Projected Inflow and Outflow Concentrations for Cu and Zn for each of the four proposed LID Pilot Project sites. The table also includes comparable information for the proposed reference monitoring site as well as the BMP locations associated with the Navy Federal Bank construction project.

Table 4-1: Projected Inflow and Outflow Concentrations for Cu and Zn

Project	BMP Size (sf)	Estimated Drainage Area (ac)	Inflow Copper Conc. (mg/L)	Outflow Copper Conc. (mg/L)*	Inflow Lead Conc. (mg/L)	total Lead effluent conc. (mg/L)*	Inflow Zinc Conc. (mg/L)	Outflow Zinc Conc. (mg/L)*
LID Pilot Project Site 1	1,500	1.15	0.12	0.07	0.025	0.008	0.69	0.40
LID Pilot Project Site 2	800	0.50	0.12	0.07	0.025	0.008	0.69	0.40
LID Pilot Project Site 3	240	0.85	0.12	0.08	0.025	0.011	0.69	0.46
LID Pilot Project Site 4	1,600	0.70	0.12	0.06	0.025	0.008	0.69	0.40
LID Pilot Project Site 5 (Reference Site)	N/A	0.73	0.12	0.12	0.025	0.025	0.69	0.69
LID Pilot Project Site 6 (Navy Federal 1)	1,600	0.37	0.12	0.06	0.025	0.007	0.69	0.39
LID Pilot Project Site 7 (Navy Federal 2)	2,200	0.60	0.12	0.06	0.025	0.007	0.69	0.39

* These only reflect the removal of particulate-bound portions of these metals. The use of chemically-active treatment media can also reduce the filtered forms of these metals.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The project team's evaluation of the NBSD NEX commercial area identified four (4) potential pilot project sites for constructing and testing LID BMPs for metals reduction. A reference site was identified for comparing the effectiveness of the LID BMP. Two (2) additional sites may become available if construction of the Navy Federal Bank building occurs before the end of 2015. The project team recommends the selection of one LID Pilot Project in the existing parking lot of the study area, a reference monitoring location within the exiting parking lot area, and a monitoring location at the Navy Federal Bank project. Each of these sites has unique advantages and disadvantages, but they are very closely ranked against the site selection criteria. LID Pilot Project Site 1 was selected by the project team because there is no loss of parking spaces. LID Pilot Project Site 2 is a better site from the standpoint of design and monitoring. This is because the drainage areas are more clearly defined, there is the opportunity to construct a deeper and more effective bioretention cell, the monitoring is more straight forward, and the extent and characteristics of the infrastructure is much more clearly defined and known. The project is also in a highly visible location and will have high educational and outreach value. The disadvantages are that there will be a short-term impact from the construction on two (2) rows of parking and the removal of four (4) to six (6) parking spaces for the location of the BMP. The site can easily be restored to the original condition after the project is completed, if that is

desired. A summary of the characteristics of LID Pilot Project Site 1 and Pilot Project 6, which is the monitoring location at the proposed Navy Federal Bank project are described below.

> *LID Pilot Project Site 1*. This is the preferred site for construction because the site meets the key requirements for location and can be constructed with minimal or only temporary impacts to the existing infrastructure. This is providing that the sidewalk can be relocated to accommodate the construction. It is also representative of many conditions that exist at NBSD that have high parking use for private vehicles. The depth to the top of the pipe where the system ties in is approximately two (2) feet. This media depth may have to be shallower than the two (2) to three (3) feet that is preferred in order for the downstream drainage system not to back up into the cell. A backflow preventer can also be used to prevent that from occurring. That would be a final design detail. Some of the larger storms events may not be captured and treated because of the higher impervious drainage area ratio to treatment area.
>
> *LID Pilot Project 6.* This site is at the proposed Navy Federal location is selected for monitoring because it is easily accessible and is representative of the other BMPs on the Navy Federal project site. The bioretention cells at the Navy Federal project site can be considered to be a representative size, configuration, and material that are used in the San Diego region to address typical non-point source stormwater runoff. There are some concerns about monitoring the locations at the Navy Federal project. The media has not specifically been selected to reduce the loads of the targeted metals. The specifications on the media are not very clear and the project team may not be able to conduct construction observation, shop drawing, and materials review in order to determine if the BMPs were built according to plan. Additional testing on the bioretention media will be required to determine the effectiveness of the system. There are also outfall issues because the discharge pipes are undersized and may affect the monitoring process as water backs up into the system.

The final selection of the site, or sites, to be constructed will be based on amount of the overall construction and monitoring budgets, and a joint evaluation by of the selection criteria by the Base Commanding Officer, Public Works Officer, and the Base Environmental staff.

6.0 REFERENCES

Clark, S. and R. Pitt. 1999. Stormwater Runoff Treatment: Evaluation of Filtration Media. EPA 600/R-00/010.EPA/600/R-99/017.U.S. Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory, Cincinnati, Ohio.405 pages.

Clark, S. and R. Pitt. 2012. Targeting Treatment Technologies to Address Specific Stormwater Pollutants and Numeric Discharge Limits. Water Research.Vol.46, Iss.20, 2012. pp.6715-6730.

Cohen, A.D., Rollins, M.S., Zunic, W.M., and J.R. Durig. 1991. Effects of Chemical and Physical Differences in Peats on Their Ability to Extract Hydrocarbons from Water. Water Research 25 (9), 1047-1060.

Evangelou, V.P. 1998. Environmental Soil and Water Chemistry: Principles and Applications. John Wiley & Sons, Inc, New York, NY. ISBN: 0-471-16515-8. 580 pages.

Gleason, D. and A.P Davis. 2013. "Effective Stormwater Treatment using Recycled Material Media," *ASCE World Environmental & Water Resources Congress '13*, Cincinnati, OH, May 20, 2013.

Morquecho, R. 2005. *Pollutant Associations with Particulates in Stormwater*. Ph.D. dissertation, Department of Civil and Environmental Engineering, the University of Alabama, 2005. 229 pgs.

Naval Facilities Engineering Command, 2010. Uniform Facilities Criteria Low Impact Development 3-210-10, Naval Facilities Engineering Command, Washington, D.C.

Ogburn, O. N. L. *Stormwater Runoff Contamination Associated with Gutter and Pipe Material Degradation*. Ph.D. dissertation, Department of Civil and Environmental Engineering, the University of Alabama, 2013. 988 pgs.

Pitt, R., Robertson, B., Barron, P., Ayyoubi, A., and S. Clark. 1999. *Stormwater Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT)*. U.S. Environmental Protection Agency, Wet Weather Flow Management Program, National Risk Management Research Laboratory. EPA/600/R-99/017. Cincinnati, Ohio. 505 pgs. March 1999.

Pitt, R. 2014. The Use of WinSLAMM at Naval Bases to Predict Stormwater Pollutant Sources and to Identify Treatment Options. U.S. Navy, NESDI, SPAWAR Systems Center Pacific, San Diego, CA 92152. February 17, 2014. 211 pgs.

Pitt, R. and S. Clark. 2010. Evaluation of Biofiltration Media for Engineered Natural Treatment Systems. Geosyntec Consultants and The Boeing Co., 1050 pages. June 5, 2010, http://www.boeing.com/aboutus/environment/santa_susana/water_quality/tech_reports/techreports_10-10-19_FinalMediaReport051010.pdf.

Sharma, D.C., and C.F. Forster. 1993. Removal of Hexavalent Chromium Using Sphagnum Peat Moss. Water Research 27 (7), 1201-1208.

Watts, R.J. 1998. Hazardous Wastes: Sources, Pathways, Receptors. Wiley, Inc., New York, NY. ISBN-10: 0471002380. 764 pages.

LID Implementation Evaluation
MS4 Structures in Study Area
Naval Base 32nd Street Commissary
San Diego, California

Geosyntec consultants

Figure 1

San Diego | Feb 2015

Naval Base 32nd Street Commissary - Field Survey Summary (02/11/2015)

I.D.	Description	Attribute Description	Diameter / Dimensions
GEO-1	Curb inlet along S 29th St. Located in SW portion of the facility.	Manhole	2 ft diameter
		Cub cut	68" wide x 9" high
		Pipe	16" diameter
		Basin Depth	42"
GEO-2	Grate with drop inlet, located adjacent to fenceline at southern end of concrete swale.	Grate	24" x 24"
		Pipe	12" diameter
		Basin Depth	18"
GEO-3	Curb inlet along S 29th St. Square concrete instead of manhole. Located in SW portion of facility, along fenceline. Unable to open concrete cover.	concrete cover	26" x 26"
		Cub cut	72" wide x 9" high
		Pipe	16" diameter
		Basin Depth	32"
GEO-4	Curb inlet along S 29th St. Located in SW portion of facility.	Manhole	24" diameter
		Curb cut	185" wide x 6" high
		Pipe	24" diameter
		Basin Depth	36"
GEO-5	Catch basin in NW parking lot of facility.	Grate	36" x 42"
		Pipe	12" diameter
		Basin Depth	36"
GEO-6	Catch basin in NW parking lot of facility.	Grate	34" X 28"
		Pipe (square)	12" high x 9" wide
		Basin Depth	34"
GEO-7	Catch basin in NW parking lot of facility.	Grate	27" x 34"
		Pipe (square)	12" high x 10" wide
		Basin Depth	31"
GEO-8	Catch basin in NW parking lot of facility.	Grate	34" X 28"
		Pipe	12" diameter
		Basin Depth	26"
GEO-9	Catch basin in NW parking lot of facility.	Grate	27" x 27"
		Pipe	10" diameter
		Basin Depth	24"
GEO-10	Catch basin in North parking lot of facility.	Grate	42" x 40"
		Pipe	12" diameter
		Basin Depth	12"
GEO-11	Cleanout in gravel at NE portion of facility.	Manhole	24" diameter
		Pipe	32" diameter
		Basin Depth	108"
GEO-12	Catch basin in North parking lot of facility. Pipe enters bottom of basin.	Grate	42" x 42"
		Pipe	12" diameter
		Basin Depth	11"
GEO-13	Catch Basin in gravel swale at SE corner of commissary. Pipe enters bottom of basin.	Grate	42" x 42"
		Pipe	12" diameter
		Basin Depth	8"

*All pipe measurements are approximate.

Naval Base 32nd Street Commissary - Field Survey Summary (02/11/2015)

I.D.	Description	Attribute Description	Diameter / Dimensions
GEO-14	Catch basin in North parking lot of facility.	Grate	42" x 42"
		Pipe	16 " diameter
		Basin Depth	48"
GEO-15	Catch basin in North parking lot of facility.	Grate	114" x 26"
		Pipe	3' diameter
		Basin Depth	76"
GEO-16	Cleanout in North parking not of facility.	Manhole	22" diameter
		Pipe	3' diameter
		Basin Depth	96"
GEO-17	Curb inlet along road in front of the food court.	Manhole	16"
		Curb cut	170" wide x 7" high
		Pipe	15" diameter
		Basin Depth	32"
GEO-18	Cleanout at NE corner of food court. 2nd pipe discharging into cleanout.	Manhole	
		Pipe from east	16" diameter
		N-S pipe	29" diameter
		Basin Depth	112"
GEO-19	Manhole cover with 2 pipes. In sidewalk @ NEX. Manhole cover marked with an "S"	Manhole	
		N-S Pipe	36" diameter
		E-W Pipe	greater than 36" diameter
		Basin Depth	9'
GEO-20	Cleanout in newly paved credit union parking lot. Four pipes entering cleanout. Unable to determine where all pipes connected.	Manhole	26" diameter
		N-S Pipe	3' diameter
		SW angle	18" - 24"
		E-W Pipe	12" diameter
		E-W Pipe	6" diameter located 2' below grade
		Basin Depth	92"
GEO-21	Catch basin east of 3629 Bld.	Pipe	8" diameter
		Grate	28" x 28"
		Basin Depth	16"
GEO-22	Curb Inlet along Colton Ave.	Manhole	
		Curb Cut	112" wide x 6" high
		Pipe	18" diameter
		Basin Depth	52"
GEO-23	Former curb inlet, redevelopment has occurred, manhole still accessible.	Pipe	18" diameter
		Basin Depth	42"
GEO-24	Cleanout in Colton Ave and S 29th St. Unable to open manhole		
GEO-25	Catch basin north of Commissary.	Grate	28" x 28"
		Pipe	8" diameter
		Basin Depth	20"

*All pipe measurements are approximate.

Naval Base 32nd Street Commissary - Field Survey Summary (02/11/2015)

I.D.	Description	Attribute Description	Diameter / Dimensions
GEO-26	3 Manholes in series labeled "Interceptor", north side of commissary, south of Lehandy Rd, Albaene Alley.		
GEO-27	Catch Basin in gravel swale at SE corner of commissary. Pipe enters bottom of basin.	Pipe	10" approximately
		Basin Depth	12" approximately

*All pipe measurements are approximate.

Preliminary Opinion of Cost				
NBSD LID Project				
March 11, 2015				
Project One	Unit	Quant	Cost	Subtotal
General				
Engineering and Survey	ls	1	$ 5,000.00	$ 5,000.00
Mobilization	ls	1	$ 5,000.00	$ 5,000.00
Construction disposal	ls	1	$ 3,000.00	$ 3,000.00
Sediment control				
Silt Fence	lf	100	$ 3.00	$ 300.00
Inlet Protection	ea	1	$ 248.00	$ 248.00
Temporary fencing	lf	100	$ 6.00	$ 600.00
Earthwork				
Excavate and export	cy	40	$ 44.00	$ 1,760.00
Fill	cy	25	$ 10.00	$ 250.00
Sitework				
Pavement Removal	sf	75	$ 4.00	$ 300.00
Sidewalk removal and disposal	sf	100	$ 2.00	$ 200.00
Aggregate Base	sf	120	$ 2.00	$ 240.00
Deep curb	lf	60	$ 26.00	$ 1,560.00
Curb and gutter removal	lf	2	$ 10.00	$ 20.00
Yard Inlet	ea	1	$ 6,240.00	$ 6,240.00
4" PVC underdrain	lf	15	$ 12.00	$ 180.00
Backflow preventer	ea	1	$ 2,400.00	$ 2,400.00
Concrete sidewalk	sf	120	$ 8.00	$ 960.00
Asphalt repair	lf	100	$ 3.00	$ 300.00
Additional crew days	ea	2	$ 1,500.00	$ 3,000.00
Landscape				
Bioretention Media	cy	22	$ 50.00	$ 1,100.00
Gravel Drainage Layer	cy	13	$ 50.00	$ 650.00
Mulch	sy	14	$ 8.00	$ 112.00
Groundcover and grassses	ea	106	$ 9.00	$ 954.00
Subtotal				$ 34,374.00
25% Contingency				$ 8,593.50
Total				$ 42,967.50

Preliminary Opinion of Cost				
NBSD LID Project				
March 16, 2015				
Project Two	Unit	Quant	Cost	Subtotal
General				
Engineering and Survey	ls	1	$ 5,000.00	$ 5,000.00
Mobilization	ls	1	$ 5,000.00	$ 5,000.00
Construction disposal	ls	1	$ 3,000.00	$ 3,000.00
Traffic Control	ea	1	$ 1,000.00	$ 1,000.00
Sediment control				
Silt Fence	lf	100	$ 3.00	$ 300.00
Inlet Protection	ea	1	$ 248.00	$ 248.00
Temporary fencing	lf	100	$ 6.00	$ 600.00
Earthwork				
Excavate and export	cy	64	$ 44.00	$ 2,816.00
Fill	cy	22	$ 10.00	$ 220.00
Sitework				
Pavement Removal	sf	110	$ 4.00	$ 440.00
Aggregate Base	sf	110	$ 2.00	$ 220.00
Deep curb	lf	100	$ 26.00	$ 2,600.00
Curb and gutter removal	lf	4	$ 10.00	$ 40.00
Reconfigure Inlet	ea	1	$ 450.00	$ 450.00
4" PVC underdrain	lf	10	$ 12.00	$ 120.00
Backflow preventer	ea	1	$ 2,400.00	$ 2,400.00
Asphalt repair	lf	120	$ 3.00	$ 360.00
Additional crew days	ea	2	$ 1,500.00	$ 3,000.00
Landscape				
Bioretention Media	cy	32	$ 50.00	$ 1,600.00
Gravel Drainage Layer	cy	22	$ 50.00	$ 1,100.00
Mulch	sy	12	$ 8.00	$ 96.00
Groundcover and grassses	ea	80	$ 9.00	$ 720.00
Subtotal				$ 31,290.00
25% Contingency				$ 7,822.50
Total				$ 39,112.50

Preliminary Opinion of Cost				
NBSD LID Project				
March 16, 2015				
Project Three	Unit	Quant	Cost	Subtotal
General				
Engineering and Survey	ls	1	$ 5,000.00	$ 5,000.00
Mobilization	ls	1	$ 5,000.00	$ 5,000.00
Construction disposal	ls	1	$ 3,000.00	$ 3,000.00
Traffic Control	ea	1	$ 1,000.00	$ 1,000.00
Sediment control				
Silt Fence	lf	120	$ 3.00	$ 360.00
Inlet Protection	ea	1	$ 248.00	$ 248.00
Temporary fencing	lf	120	$ 6.00	$ 720.00
Earthwork				
Excavate and export	cy	15	$ 44.00	$ 660.00
Fill	cy	5	$ 10.00	$ 50.00
Sitework				
Pavement Removal	sf	120	$ 4.00	$ 480.00
Aggregate Base	sf	120	$ 2.00	$ 240.00
Deep curb	lf	40	$ 26.00	$ 1,040.00
Curb and gutter removal	lf	2	$ 10.00	$ 20.00
Reconfigure Inlet	ea	1	$ 450.00	$ 450.00
4" PVC underdrain	lf	18	$ 12.00	$ 216.00
Backflow preventer	ea	1	$ 2,400.00	$ 2,400.00
Asphalt repair	lf	120	$ 3.00	$ 360.00
Additional crew days	ea	2	$ 1,500.00	$ 3,000.00
Landscape				
Bioretention Media	cy	10	$ 50.00	$ 500.00
Gravel Drainage Layer	cy	10	$ 50.00	$ 500.00
Mulch	sy	13	$ 8.00	$ 104.00
Groundcover and grassses	ea	100	$ 9.00	$ 900.00
Subtotal				$ 26,228.00
25% Contingency				$ 6,557.00
Total				$ 32,785.00

Preliminary Opinion of Cost				
NBSD LID Project				
March 16, 2015				
Project Four	Unit	Quant	Cost	Subtotal
General				
Engineering and Survey	ls	1	$ 5,000.00	$ 5,000.00
Mobilization	ls	1	$ 5,000.00	$ 5,000.00
Construction disposal	ls	1	$ 3,000.00	$ 3,000.00
Traffic Control	ea	1	$ 1,000.00	$ 1,000.00
Sediment control				
Silt Fence	lf	80	$ 3.00	$ 240.00
Inlet Protection	ea	1	$ 248.00	$ 248.00
Temporary fencing	lf	80	$ 6.00	$ 480.00
Earthwork				
Excavate and export	cy	25	$ 44.00	$ 1,100.00
Fill	cy	10	$ 10.00	$ 100.00
Sitework				
Pavement Removal	sf	200	$ 4.00	$ 800.00
Aggregate Base	sf	200	$ 2.00	$ 400.00
Deep curb	lf	100	$ 26.00	$ 2,600.00
Curb and gutter removal	lf	4	$ 10.00	$ 40.00
4" PVC underdrain	lf	10	$ 12.00	$ 120.00
Backflow preventer	ea	1	$ 2,400.00	$ 2,400.00
Asphalt repair	lf	300	$ 3.00	$ 900.00
Additional crew days	ea	2	$ 1,500.00	$ 3,000.00
Landscape				
Bioretention Media	cy	14	$ 50.00	$ 700.00
Gravel Drainage Layer	cy	14	$ 50.00	$ 700.00
Mulch	sy	20	$ 8.00	$ 160.00
Groundcover and grassses	ea	150	$ 9.00	$ 1,350.00
Subtotal				$ 29,338.00
25% Contingency				$ 7,334.50
Total				$ 36,672.50

APPENDIX B

R. Pitt
March 30, 2016

Bioretention and Porous Pavement Overflow and Underdrain Flow Conditions

Summary

WinSLAMM was used to evaluate the potential overflow and underdrain flow conditions of the demonstration porous pavement and biofilter (bioretention) sites at NBSD. Site and design information were incorporated into the WinSLAMM model for these devices and evaluated using different underdrains and native soil infiltration rates. The calibrated version of WinSLAMM prepared for NBSD was used, along with San Diego airport January 1999 to December 2005 rains (248 rains from 0.01 to 2.85 inches in depth). WinSLAMM continuously evaluated these controls for these events considering both event and interevent periods.

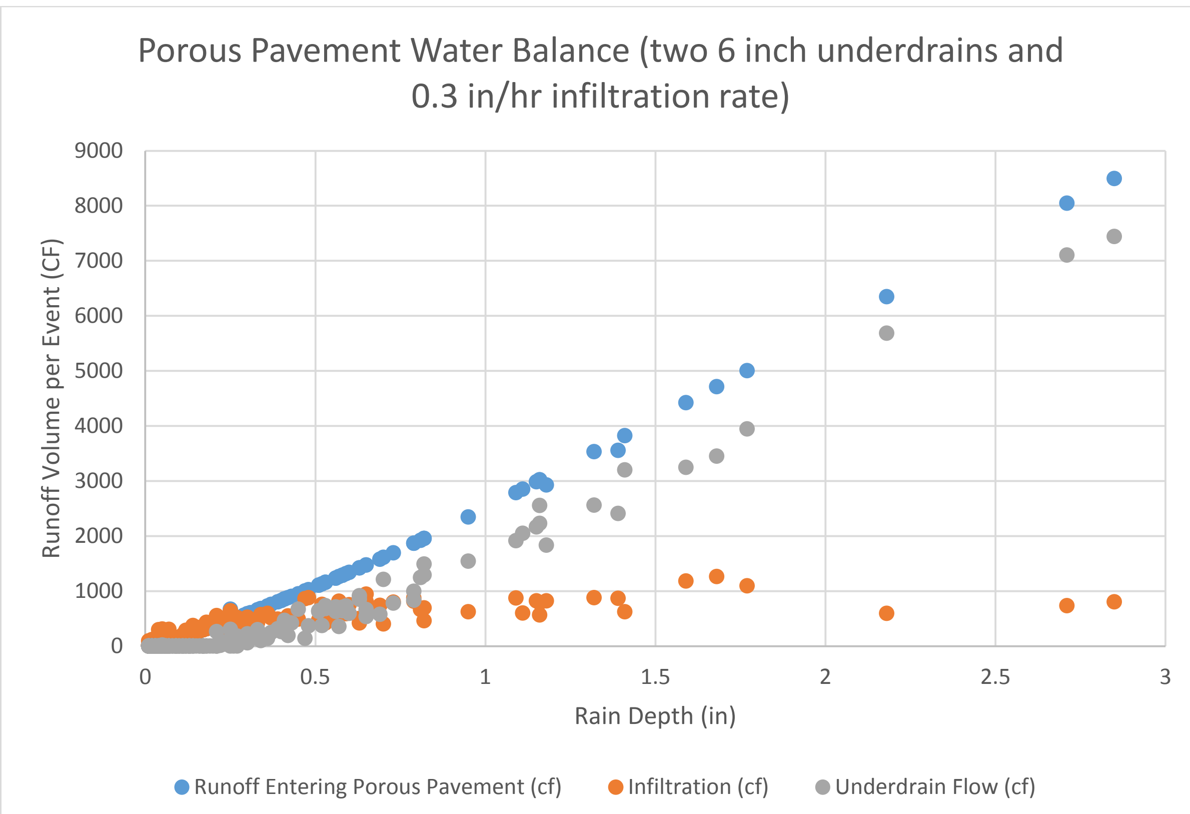
The porous pavement area is about 7% of the total paved drainage area. The model considers both direct rainfall on the porous pavement, plus the runon from the additional area. With very poor infiltrating native soils, underdrains at least 1 in in diameter (3 rows) would be suitable, providing at about 85% particulate solids capture. The use of three 3 inch underdrains would "always" be suitable to discharge any infiltrating water, with no surface overflow. Unless clogged, all rain and runoff would enter the porous pavement, with no surface overflow. However, substantial underdrain flows would occur if the native soil infiltration rates were relatively low. These analyses were therefore used to determine which rains would produce underdrain flows. The performance of the porous pavement varies greatly depending on rain intensity, interevent period, and rain depth, plus the native infiltration rates (the surface infiltration rate through the pavement surface is always high, unless clogged due to poor maintenance). The following table lists the approximate (linearized) maximum rain depths associated with at least 90% runoff reductions and for at least 50% runoff reductions for the porous pavement site. Underdrain flows of at least 10% of the total site runoff would occur for very small rains (0.01 inch rains) for clay soils, increasing to 0.75 inch rains for sandy loam soils. Loamy sand soils would be able to infiltrate all of these rains with no underdrain flows expected.

native infiltration rates (in/hr)	0.02 (clay soil)	0.1 (clay loam soil)	0.5 (loam soil)	1.0 (sandy loam soil)	2.5 (loamy sand soil)
max. rain depth for 90% runoff volume reductions (in)	0.01	0.15	0.23	0.75	all rains
max. rain depth for 50% runoff volume reductions (in)	0.75	1.0	2.0	3.0	all rains
Long-term total runoff reductions (%)	28%	43%	67%	80%	100%

The following figure plots the total runoff entering the porous pavement (for silt loam soils having 0.3 in/hr infiltration rates, the expected site condition), along with the concurrent amount of surface runoff entering the two 6 inch underdrains. Surface bypass runoff is not expected, unless premature clogging of the pavement surface occurs. The percentage fates of incoming water are calculated as:

Infiltration: 43%
Underdrain flow: 57%

Underdrain flow would be expected starting for rains of about 0.5 inches in depth for these infiltration conditions. If the infiltration rates were greater, underdrain flows would be delayed until larger rains.



Anything smaller than two 2 inch underdrains for the porous pavement system (located at the surface of the rock storage layer) would cause surface bypass flows during moderate to small rains. No soil conditions (even clay) would be expected to cause surface bypass flows from this permeable pavement facility for any of the rains in the rain series investigated. However, premature surface clogging of the pavement would cause surface bypass flows.

The biofilter is about 2% of the paved drainage area. With any if the soil conditions, the three 3 inch underdrains would not be restrictive, so these analyses indicate the rain conditions likely to produce underdrain flows for the different soil conditions. The overall runoff reductions are less than 10% with

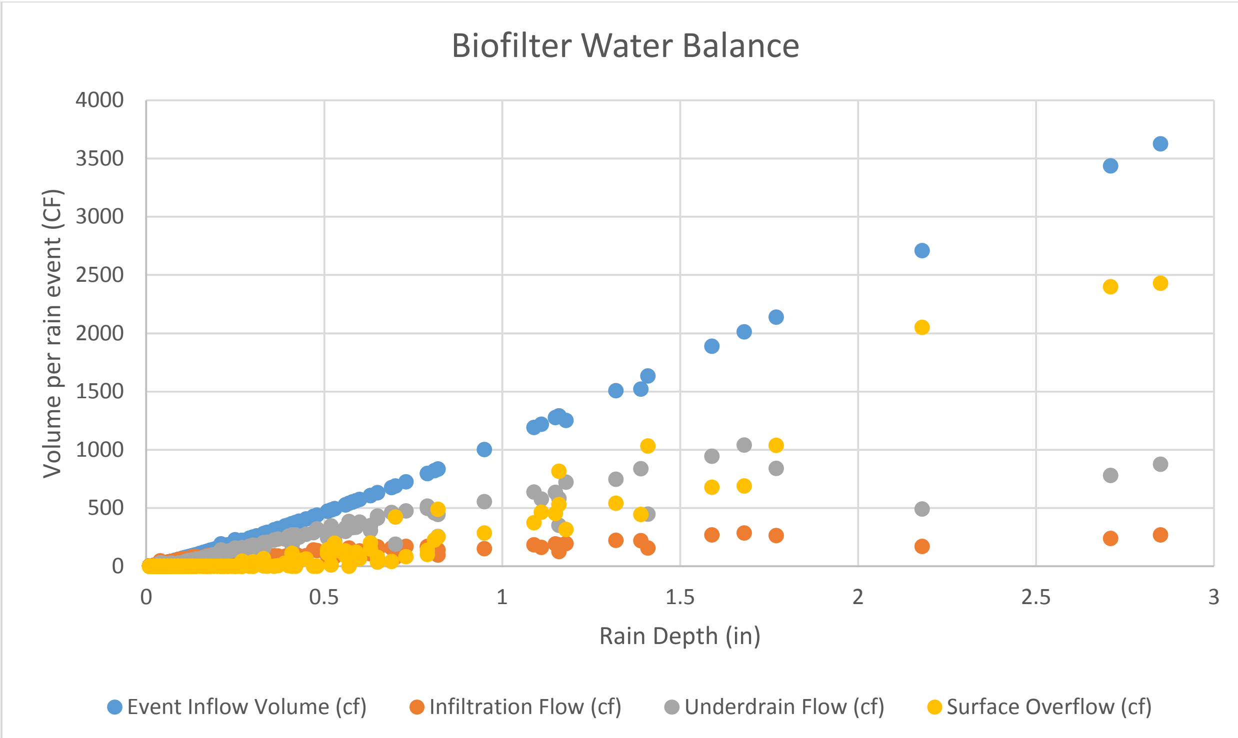
poor infiltration conditions. For 0.3 and 1 in/hr native soil infiltration rates, no underdrain could be used for the highest level of runoff volume control (about 50 or 70%, respectively, for the two infiltration rates). The underdrains would cause short-circuiting of the stormwater before it could be infiltrated, with 10 to 15% decreased runoff volume capture performance. There are less flow-duration benefits with the biofilter compared to the porous pavement site, but clogging should not be an issue (several decades of use before silting of media). The following table lists the approximate (linearized) maximum rain depths associated with at least 90% runoff reductions and for at least 50% runoff reductions for the biofilter site. Underdrain flows of at least 10% of the total site runoff would occur for very small rains (0.05 inch rains) for clay soils, increasing to 0.3 inch rains for sandy loam soils. Loamy sand soils would produce underdrain flows for rains larger than about 1.8 inches in depth.

native infiltration rates (in/hr)	0.02 (clay soil)	0.1 (clay loam soil)	0.5 (loam soil)	1.0 (sandy loam soil)	2.5 (loamy sand soil)
max. rain depth for 90% runoff volume reductions (in)	max reduction of 65%	max reduction of 80%	0.05	0.3	1.8
max. rain depth for 50% runoff volume reductions (in)	0.3	0.6	0.75	1	all rains
Long-term total runoff reductions (%)	7%	14	34	53	93

The following figure plots the total runoff entering the biofilter (for silt loam soils having 0.3 in/hr infiltration rates, the expected site condition), along with the concurrent amount of surface runoff bypassing the biofilter due to excessive ponding. Surface bypass runoff would start to occur with rains of about 0.5 inches in depth, although smaller rains may produce bypass flows depending on other rainfall characteristics and antecedent water stored in the biofilter at the start of the rain. The percentage fates of incoming water are calculated as:

Infiltration: 22% (total runoff volume reduction)
Underdrain flow: 47%
Surface overflow: 31%

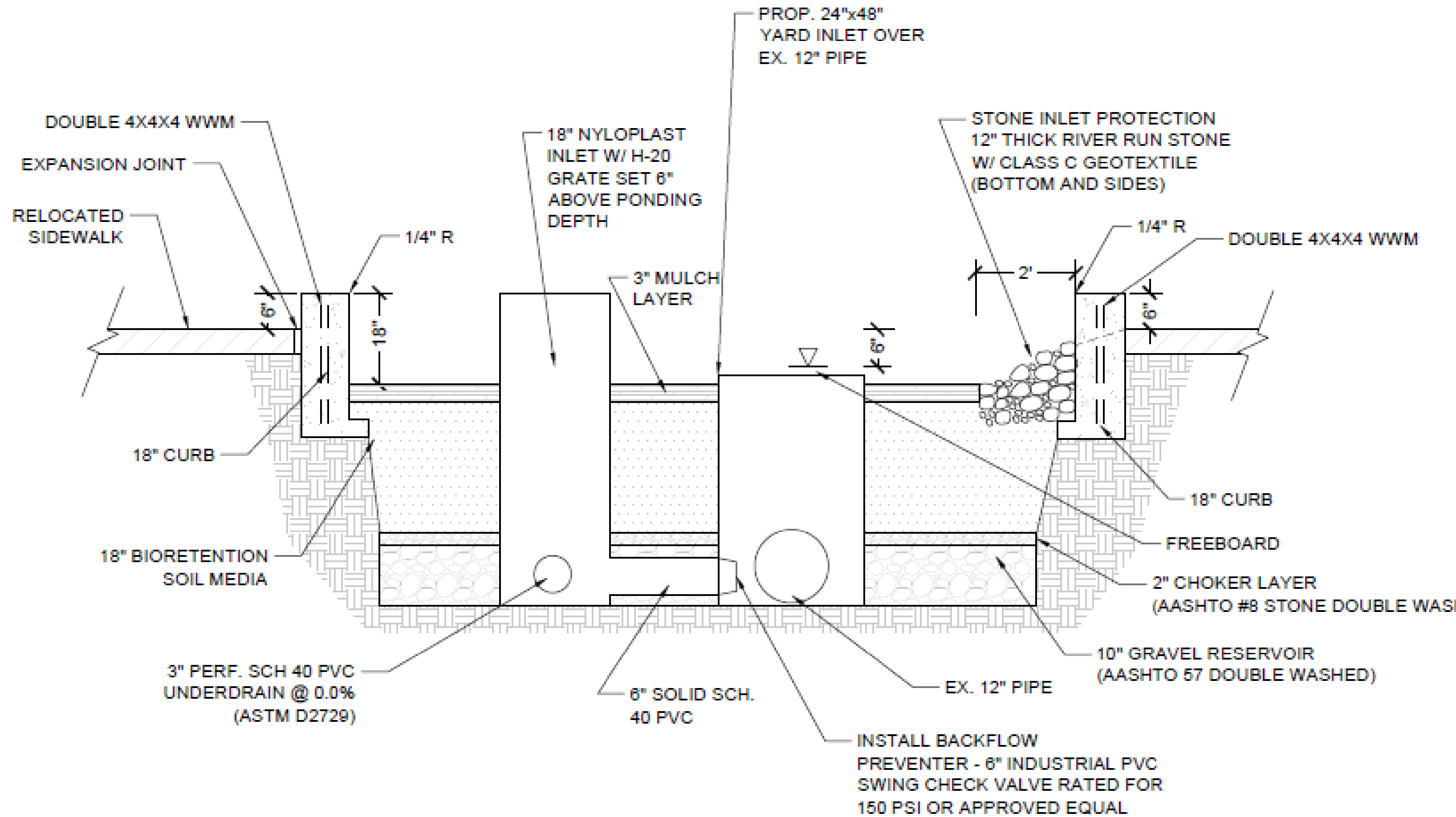
Substantial surface runoff occurs (about 25 to 50% of the total runoff volume) with 1 inch rains. Saturated conditions occur with very little additional infiltration possible after about 0.5 in rains. If the site soil infiltration conditions were greater than 0.3 in/hr, the surface bypass flows would be less and start with larger rains.



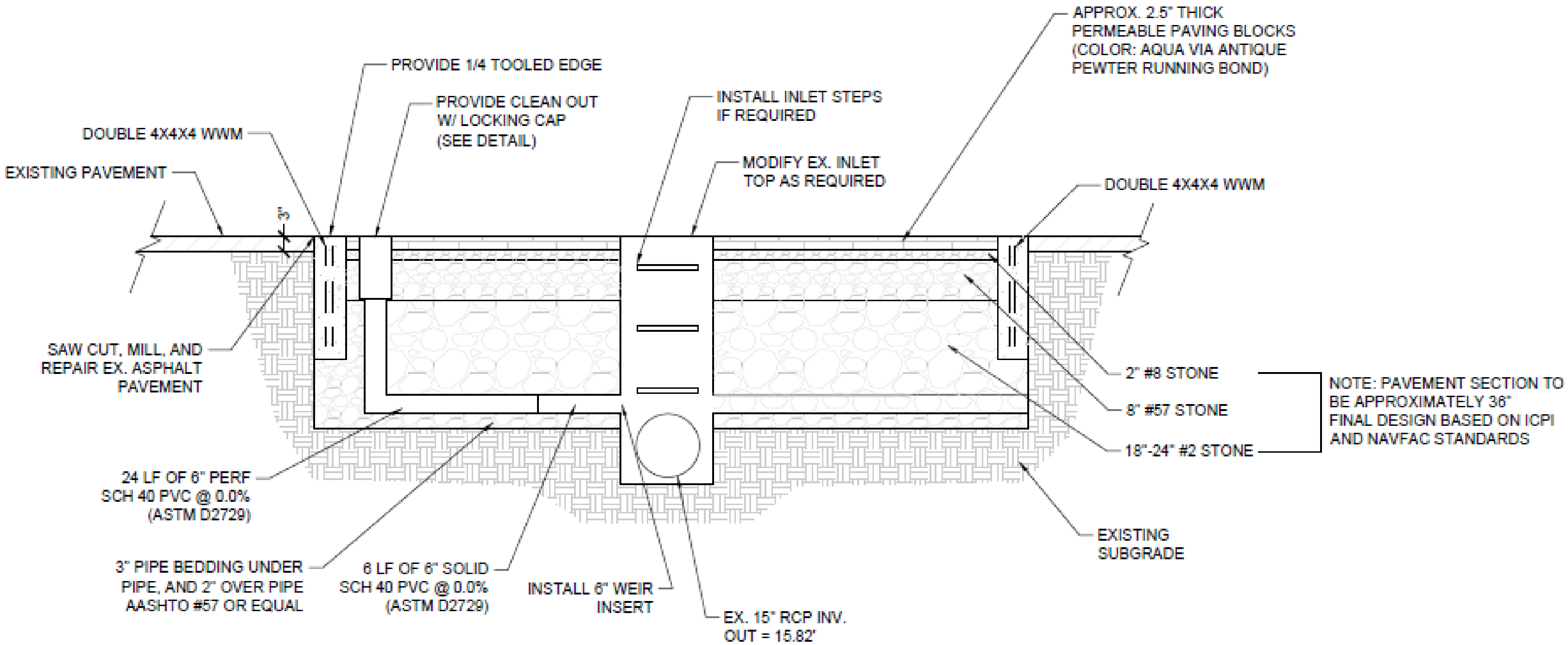
Site Information

The following table and figures were provided by the Low Impact Development Center to describe the drainage areas and treatment system characteristics. These were used to prepare the WinSLAMM input files that were analyzed to examine the effects of the different underdrain options for the porous pavement and biofilter stormwater controls.

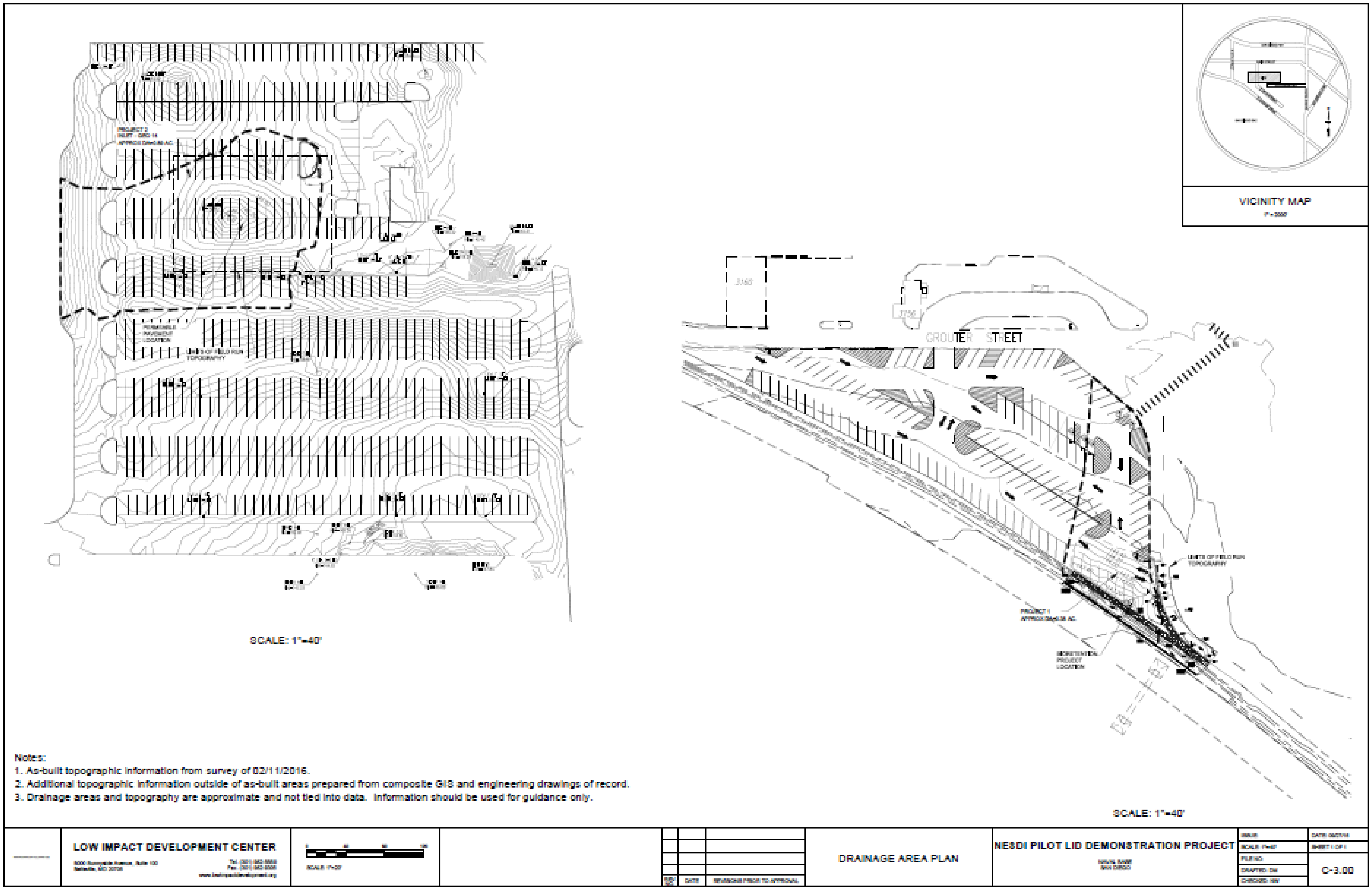
Stormwater Control	Drainage Area (ac)	Drainage Area (sf)	Surface Area (sf)	Ponding Depth (ft)	Ponding Storage (cf)	Mulch Depth (ft)	Mulch Storage (cf)	Media Depth (ft)	Media Storage (cf)	Gravel Depth (ft)	Gravel Storage (cf)	Total Storage (cf)
Bioretention	0.38	16,550	400	0.5	200	0.17	27	1.5	240	0.83	133	600
Permeable Pavement	0.89	38,750	2,800	0	0	0	0	0	0	3	3,360	3,360



Biofilter Details (Low Impact Development Center).



Permeable Pavement Details (Low Impact Development Center).

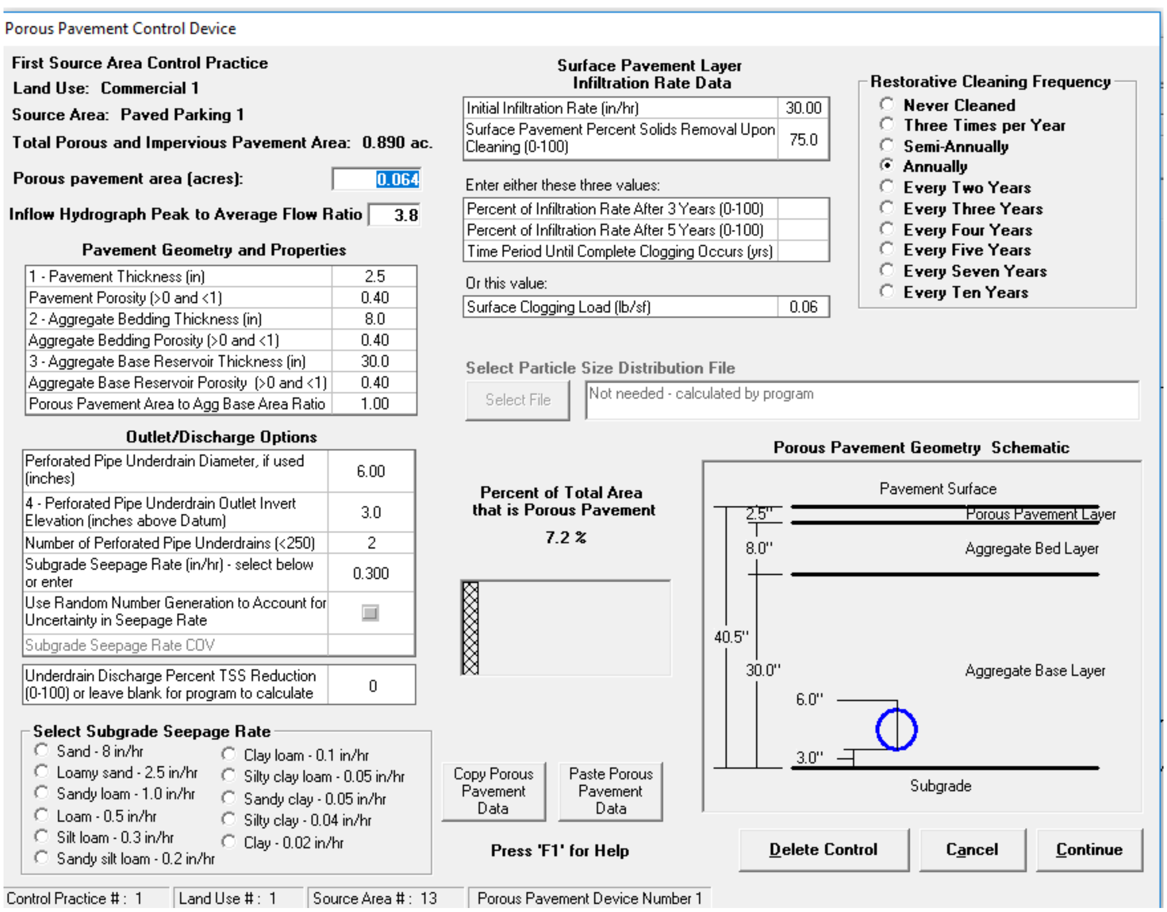


Bioretention and Porous Pavement Drainage Areas

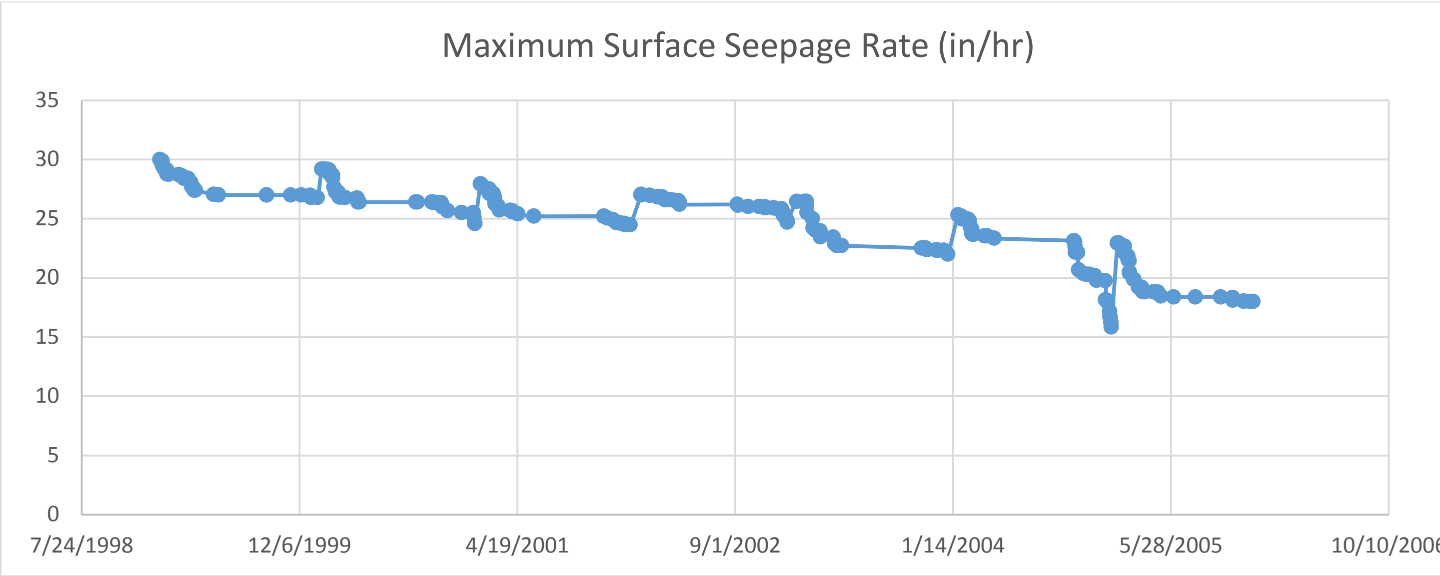
Porous Pavement Analyses

The WinSLAMM porous pavement control in version 10 has full routing calculations associated with subsurface pond storage, and it allows runon from adjacent paved areas that do not have porous pavement. The outlet options for porous pavements include subgrade seepage and an optional underdrain, which is modeled as an orifice. The porous pavement control device has a surface seepage rate that limits the amount of runoff that can enter the storage system. The seepage rate is usually much greater than the rain intensity, so this would be unusual, except if it is significantly reduced by clogging or if substantial runon occurs from adjacent paved areas. This surface seepage rate is reduced to account for clogging with time, while the surface seepage rate can be partially restored with cleaning at a stated cleaning frequency. The runoff volume reaching the porous pavement surface is equal to the rainfall volume directly falling on the porous pavement, plus runoff volume from any runon from the adjacent paved areas. The porous pavement surface can be paver blocks, porous concrete, porous asphalt, or any other porous surface, including reinforced turf. Porous pavements are usually installed over a subsurface storage layer that can dramatically increase the infiltration performance of the device.

It is necessary to describe the geometry and other characteristics of a typical porous pavement surface, as shown in the following input screen figures. The model computes the runoff volume, equal to the rainfall volume plus any runon, and then creates a complex triangular hydrograph (the flow duration equals the rain duration) that it routes through that porous pavement system.

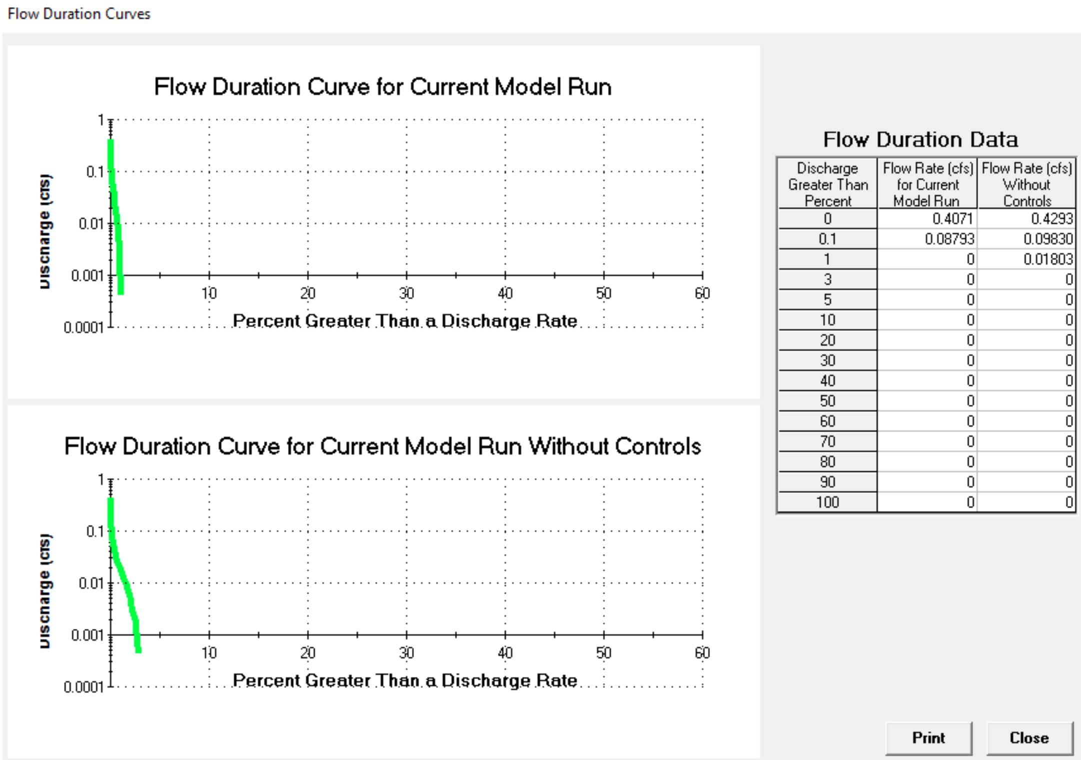


The initial pavement infiltration rate was assumed to be about 30 in/hr. With annual cleaning that can restore about 75% of the infiltration capacity (typical), the infiltration capacities decrease in time for this site, losing about 1/3 to ½ of the initial capacity after the 7 years of this model analysis. It is expected that failure may occur after 15 or 20 years, requiring replacement of the porous pavement facility (surface material and media to be replaced). Premature failure may occur due to tracking of material on the porous pavement, or other unusual conditions.



Porous Pavement Surface Infiltration Rate with Time (Annual cleaning; initial rate of 30 in/hr).

The flow-duration distributions shown below will be significantly moderated with the porous pavement. The duration of flow will decrease by about 90% (for this example for 0.3 in/hr infiltration rate and two 6 in underdrains).



Discharge Greater Than Percent	Flow Rate (cfs) for Current Model Run	Flow Rate (cfs) Without Controls
0	0.4071	0.4293
0.1	0.08793	0.09830
1	0	0.01803
3	0	0
5	0	0
10	0	0
20	0	0
30	0	0
40	0	0
50	0	0
60	0	0
70	0	0
80	0	0
90	0	0
100	0	0

The performance of the porous pavement varies greatly depending on rain intensity, interevent period, and rain depth, plus the native infiltration rates (the surface infiltration rate through the pavement surface is always high, unless clogged due to poor maintenance). The following table lists the approximate (linearized) maximum rain depths associated with at least 90% runoff reductions and for at least 50% runoff reductions.

native infiltration rates (in/hr)	0.02 (clay soil)	0.1 (clay loam soil)	0.5 (loam soil)	1.0 (sandy loam soil)	2.5 (loamy sand soil)
max. rain depth for 90% runoff volume reductions (in)	0.01	0.15	0.23	0.75	all rains
max. rain depth for 50% runoff volume reductions (in)	0.75	1.0	2.0	3.0	all rains
Long-term total runoff reductions (%)	28%	43%	67%	80%	100%

Bioretention Facility Analysis

Biofilters are similar in function to rain gardens but have more complex cross-sections with increased water volume storage that enhances their performance. They are excavations to collect runoff and allow infiltration. They are usually filled with a rock storage layer, and treatment layer, and most have underdrains to prevent excessive ponding for extended times. Because of the increased amount of storage compared to a simple rain garden, biofilters can better handle short periods of increased runoff and larger amounts of runoff.

Biofilter performance is based on the characteristics of the flow entering the device, the infiltration rate into the native soil, the filtering capacity and infiltration rate of the engineered media fill if used, the amount of rock fill storage, the size of the device and the outlet structures for the device. Pollutant filtering by the engineered media (usually containing amendments) is based on the engineered media type and the particle size distribution of the particulates in the inflowing water. If the engineered media flow rate is lower than the flow rates entering the device, the engineered media will affect the device performance by forcing the excess water to bypass the device through surface discharges, if the storage capacity above the engineered media is inadequate.

The device operation is modeled using the Modified Puls Storage-Indication method and is analyzed differently depending on whether a rock and engineered media layer is in the model. The model simulates the inflow and outflow hydrographs using a time interval selected by the user (typically 6 minutes), although this interval is reduced automatically by the program if the simulation calculations approach becoming unstable.

The inflow hydrograph is divided into the selected time intervals, which are routed to the surface of the biofilter. The biofilter is evaluated in two basic sections: the aboveground section (or above the engineered media) and the belowground section (below the surface of the engineered media). If there is a rock layer and an engineered media layer, separate details are entered for each. The available surface outflow devices include broad crested weirs (required to have at least one as the surface overflow outlet), and optional crested weirs, vertical stand pipes, and evaporation/ET. An underdrain is also optional that discharges back to the drainage system (but with “filtered” water).

As water enters the device, the water infiltrates through the media to the belowground section if the engineered media infiltration rate is greater than the inflowing water rate. If the inflow rate increases to be greater than the media infiltration rate, the aboveground storage begins to fill. If the inflowing rate is high enough and the excess runoff volume exceeds the available storage, the water discharges from the device through the aboveground surface broad crested weir outflow, and any other surface outlet. As water enters the belowground section of the device, it passes through the native soil and, as the bottom section fills, it may enter an underdrain (if used). All water that flows through the underdrain is assumed to be filtered by the engineered media. The filtering performance changes based on the type of engineered media and varies by the particle size of the particulates in the water. If the water level in the belowground section of the device reaches the top of the engineered media layer, infiltration from the surface layer into the belowground layer stops until the water level in the belowground section is below the top of the engineered media layer. If there are no rock and engineered media layers, flow into the native soil is considered to be an outflow: there is no belowground section, and all treatment by the

device is assumed to be through volume loss by infiltration into the native soil (this is the typical way rain gardens operate, since they have no media or underdrain, but do have surface storage).

The following figures are the data entry forms used for biofilters and related stormwater controls. To model biofilters, the geometry and other characteristics of the biofilter are described, or of a typical biofilter if modeling a set of biofilters for, say, roofs or parking lot source areas. The number of biofilters to be modeled in the source area is also entered on the form. The model divides the total source area runoff volume by the number of biofilters in the source area, creates a complex triangular hydrograph for that representative flow fraction that is then routed through that biofilter. It then multiplies the resulting runoff pollutant and flow reductions by the number of biofilters for the total source area effects.

Device Geometry:

Top Area (square feet): Enter the top area of the biofilter

Bottom Area (square feet): Enter the bottom area of the biofilter

Total Depth (feet): Enter the depth of the biofilter.

Typical Width (ft): If you intend to perform a cost analysis of the biofilter practices listed in the .mdb file, you must enter the typical biofilter width (ft) of a biofilter system you are modeling. This value is not used for a hydraulic or water quality analysis; it is relevant only for the cost analysis.

Native Soil Infiltration Rate (in/hr): Enter the infiltration rate or select a typical infiltration rate based on soil type from the provided list in the lower left-hand corner of the window. The native soil infiltration rate value is supplied if you select the typical seepage rate provided by the model.

Native Soil Infiltration Rate COV (Coefficient of Variation): If you want to consider the typical variabilities in the infiltration rates, select the “Use Random Number Generation to Account for Uncertainty in Infiltration Rate” checkbox and then accept or enter another seepage rate COV value in the cell below the native soil infiltration rate. This is optional and uses a Monte Carlo simulation built into the model. If selected, the infiltration rates are randomly varied for each event based on a log-normal probability distribution of actual measured infiltration rate variabilities.

Infiltration Rate Fraction - Bottom (0-1): Enter the seepage rate multiplier for bottom flow (from 0 to 1) to reduce the seepage rate through the bottom of the biofilter. This option can be useful if you want to evaluate the effects of complete clogging on the bottom of the device.

Infiltration Rate Fraction - Side (0-1): Enter the seepage rate multiplier for side flow (from 0 to 1) to reduce the seepage rate through either the sides of the biofilter. This option can be useful if you want to ignore the benefits of seepage out of the sides of the device, as required by some regulatory agencies.

Rock Filled Depth (ft): This is the depth of biofilter that is rock filled. This must be less than or equal to the biofilter depth, and may be zero if there is no rock fill. Water is assumed to flow through the rock storage layer very quickly.

Rock Fill Porosity: Enter the fraction of rock fill that is voids as a value from zero to one. If you have both rock fill and engineered soil, the model sums the total pore volume available in the biofilter. If you are using an underdrain, a rock storage layer will be required (and the underdrain is usually

located near the top of this storage layer, but can be at the bottom if there is no natural infiltration, or for a sealed system).

Engineered Media Type. If the device has an engineered soil layer, the program uses an infiltration rate depending on the type of engineered media, based on extensive media tests in laboratory columns and in the field. Select the 'Media Data' button to enter media type information including the media porosity, infiltration rate, field moisture capacity and permanent wilting point.

Engineered Media Infiltration Rate (in/hr): If you have selected a specific engineered media type, the program uses an infiltration rate for that media type, or if you selected a user defined media type, you may enter your own engineered media infiltration rate.

Engineered Media Depth (ft). This must be less than or equal to the biofilter depth, and may be zero if there is no engineered media fill.

Engineered Media Porosity (0-1): This is the fraction of engineered media that is voids - enter the porosity of the engineered media as a value from zero to one. If you have both rock fill and engineered media, the model sums the total pore volume from all layers.

Percent Solids Reduction Due to Engineered Media. If you want to enter a percent solids reduction value from engineered media if permitted to do so by the regulatory agency or because you have suitable data, select "User-Defined" as the engineered media type in the Detailed Soil Characteristics form. If you select any other engineered media type, the program calculates the particulate solids reductions based on the media type and stormwater characteristics.

Inflow Hydrograph Peak Flow to Average Flow Ratio. This value is used to determine the shape of the complex triangular unit hydrograph that is routed through the device. A typical value of the peak to average flow ratio is 3.8. However, short duration events in small areas may have larger ratios and similarly, long duration events in large areas may have smaller ratios. In version 10, it is recommended that the option to use the routed hydrograph from upgradient areas and controls be selected instead of setting this value to 3.8.

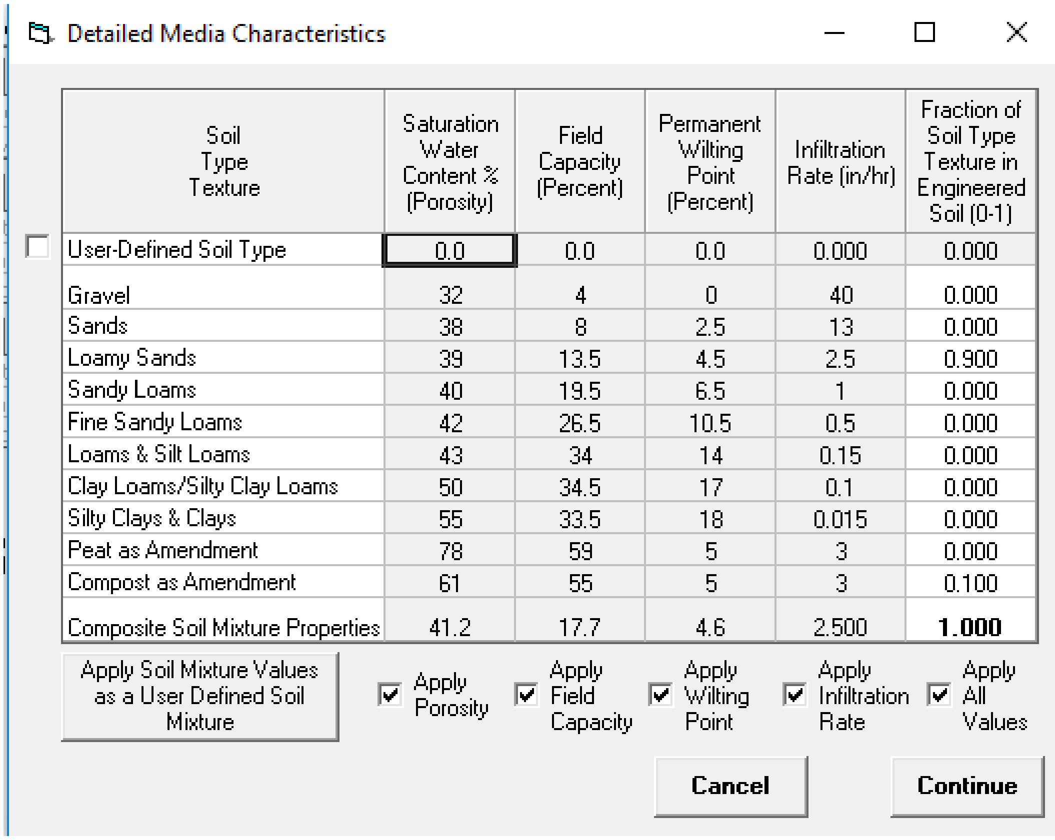
Number of Devices in the Source Area or Upstream Drainage System (all assumed to be similar with similar drainage areas, otherwise enter them separately). The model divides the runoff volume by the number of biofilters in the source area or land use, creates a complex triangular hydrograph that it routes through that biofilter, and then multiplies the resulting losses by the number of biofilters to apply the results to the source area.

Particle Size Distribution File. The particle size distribution of the particulates in the runoff affects the percent solids reduction of the engineered media layer. If you select the 'Route Hydrographs and Particle Sizes between Control Devices' checkbox in Program Options/Default Model Options (recommended), the program uses the routed particle size distributions from upgradient source areas. The particle size distribution entering the control device is modified by whatever practices are upstream of the control practice. If the practice is the most upstream practice, the initial particle size distribution is used.

Pipe or Box Storage is not activated in this model version.

The following figure is a screen shot used to select the engineered media mixture. The model calculated the porosity, field capacity, wilting point, and infiltration rates for many combinations based on

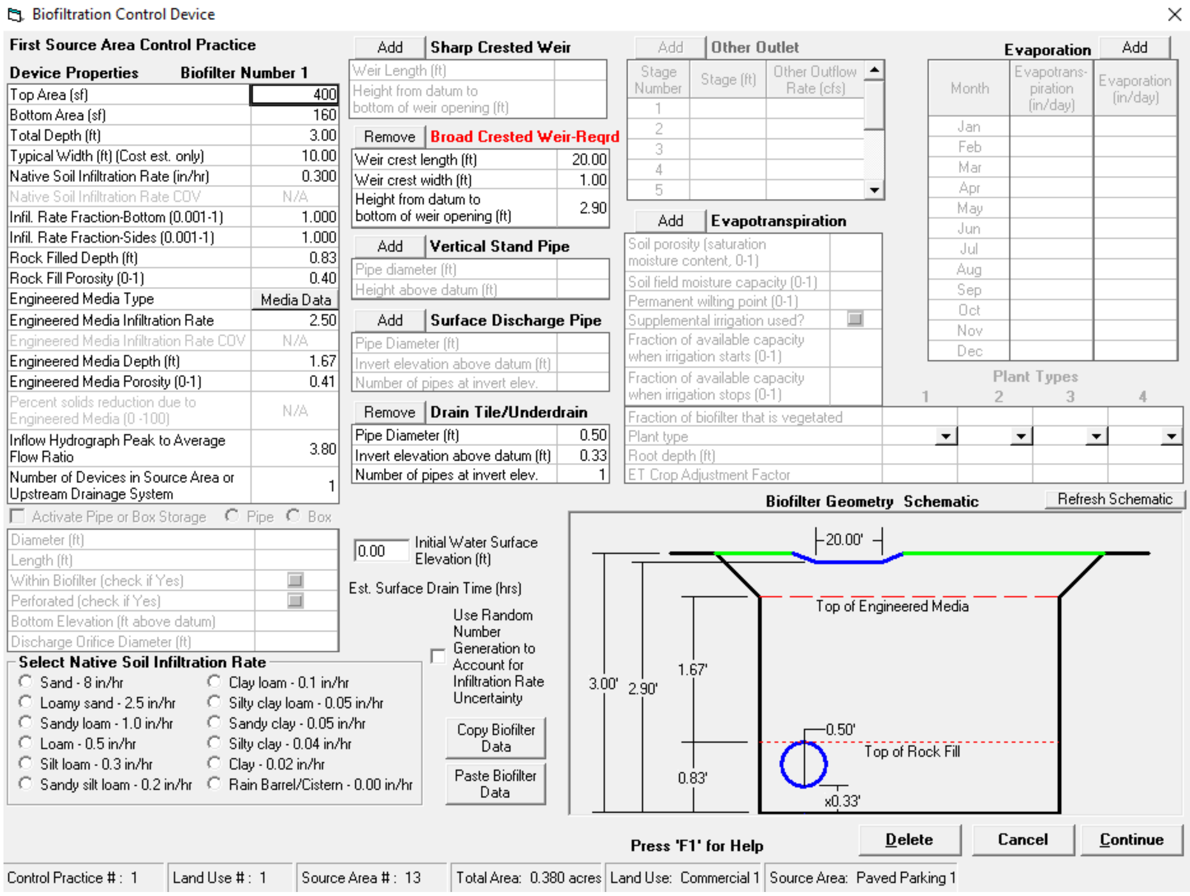
laboratory and field tests. The model also calculates the removal of different sized particles in the runoff based on the media mixture and stormwater characteristics.


Detailed Media Characteristics

Soil Type Texture	Saturation Water Content % (Porosity)	Field Capacity (Percent)	Permanent Wilting Point (Percent)	Infiltration Rate (in/hr)	Fraction of Soil Type Texture in Engineered Soil (0-1)
User-Defined Soil Type	0.0	0.0	0.0	0.000	0.000
Gravel	32	4	0	40	0.000
Sands	38	8	2.5	13	0.000
Loamy Sands	39	13.5	4.5	2.5	0.900
Sandy Loams	40	19.5	6.5	1	0.000
Fine Sandy Loams	42	26.5	10.5	0.5	0.000
Loams & Silt Loams	43	34	14	0.15	0.000
Clay Loams/Silty Clay Loams	50	34.5	17	0.1	0.000
Silty Clays & Clays	55	33.5	18	0.015	0.000
Peat as Amendment	78	59	5	3	0.000
Compost as Amendment	61	55	5	3	0.100
Composite Soil Mixture Properties	41.2	17.7	4.6	2.500	**1.000**

Screen shot of bioretention media screen showing mixture assumed for site (10% compost and 90% loam soil).

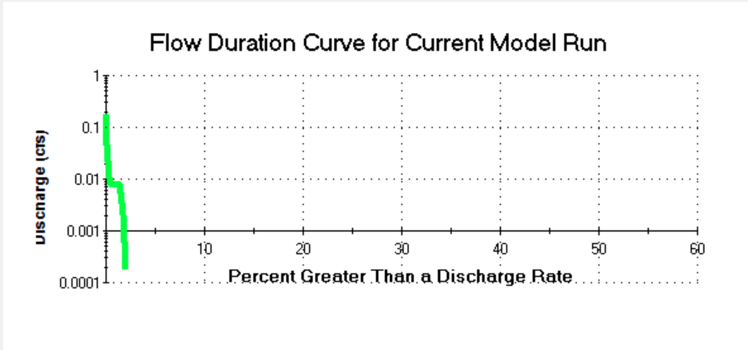
The resulting media infiltration rate is estimated to be about 2.5 in/hr, and the porosity is estimated to be about 0.4. No plants were used in this analysis so the wilting point value was not used in the media moisture calculations.

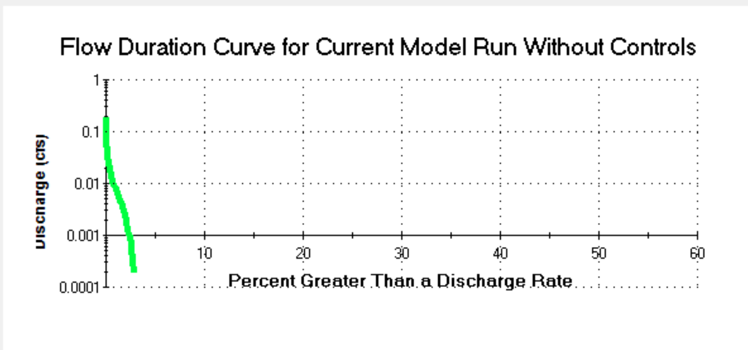


Bioretention System Input Screen (0.3 in/hr native soil infiltration rate and 6 inch underdrain)

The shape of the flow-duration graphs below for with and without treatment (1X6 in underdrains and 0.3 in/hr native soil infiltration rate) are quite different, but the actual flows for peak, 0.1% and 1% durations are similar. Even though the peak discharge rate are similar, the flows drop quickly to moderate flows.

Flow Duration Curves





Flow Duration Data

Discharge Greater Than Percent	Flow Rate (cfs) for Current Model Run	Flow Rate (cfs) Without Controls
0	0.1783	0.1833
0.1	0.03654	0.04197
1	0.007843	0.007698
3	0	0
5	0	0
10	0	0
20	0	0
30	0	0
40	0	0
50	0	0
60	0	0
70	0	0
80	0	0
90	0	0
100	0	0

Print Close

The calculated particulate solids loading rate for this biofilter is about 0.2 kg/m^2/yr. It would therefore require many decades of use before the total accumulative loading reached the expected clogging load of 10 to 25kg/m^2. Therefore, even with minimal plants to help incorporate the particulates into the biofilter's media, this system should not prematurely fail.

The performance of the biofilter varies greatly depending on rain intensity, interevent period, and rain depth, plus the native infiltration rates. The following table lists the approximate (linearized) maximum rain depths associated with at least 90% runoff reductions and for at least 50% runoff reductions.

native infiltration rates (in/hr)	0.02 (clay soil)	0.1 (clay loam soil)	0.5 (loam soil)	1.0 (sandy loam soil)	2.5 (loamy sand soil)
max. rain depth for 90% runoff volume reductions (in)	max reduction of 65%	max reduction of 80%	0.05	0.3	1.8
max. rain depth for 50% runoff volume reductions (in)	0.3	0.6	0.75	1	all rains
Long-term total runoff reductions (%)	7%	14	34	53	93

Geosyntec consultants

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29 September 2015

Mr. Chuck Katz
Oceanographer
Environmental Services Branch 71750
Space and Naval Warfare Systems Center Pacific
53475 Strothe Road
San Diego, CA 92152

via email: chuck.katz@navy.mil

Subject: Limited Geotechnical Design Review – Low Impact Development (LID) Demonstration Project, Naval Base San Diego (NBSD) Commercial Area, San Diego, California.

Dear Chuck:

Geosyntec Consultants (Geosyntec) is pleased to provide this letter to SPAWAR Systems Center San Diego (SPAWAR) summarizing our geotechnical conclusions and recommendations for the Low Impact Development (LID) Demonstration Project at Naval Base San Diego, Commercial Area, in San Diego, California. The purpose of our work was to provide recommendations for the aggregate materials planned beneath the permeable pavers and the bioretention cell, and address the need for liner systems. This work is being performed in accordance with our 25 September 2015 proposal.

We understand the LID demonstration best management practices (BMPs) are being constructed to assess the effectiveness of the copper and zinc removal from storm water runoff. These LID pilot BMPs are being constructed in concert with some redevelopment in the commercial area.

BMPs include a bioretention facility that uses an engineered media for constituent removal and a permeable paver area that uses a metered aggregate flow through system for constituent removal; the facilities are approximately 30 by 25 feet (ft) and 25 by 80 ft in plan dimension, respectively. Each unlined BMP extends approximately 3 ft below grade and includes piping and monitoring

ports / wells in addition to filter media and aggregate. The current design drawings[1] for the permeable paver BMP specifies some larger gravel aggregates (up to 2 1/2 inches in diameter) which is large for a flow-through BMP designed to provide a large surface area for capturing constituents.

Geotechnical investigations were not specifically performed for the BMPs. Therefore a geotechnical investigation[2] for the new Navy Federal Credit Union, located approximately 100 feet easterly of the permeable paver BMP, was reviewed for a general understanding of subsurface conditions near the BMPs. It appears that the site is underlain by fill soils varying from approximately 3 to 7 ft below the ground surface (bgs); borings nearest the BMPs recorded fill thicknesses on the order of 3 ft bgs. The fill materials are described as medium dense clayey sands, and according to the grain size distribution, may contain 40 percent silt and clay sized material. At depth, below the fill, the site is underlain by marine terrace deposits consisting of medium dense, lightly cemented silty sandstone interbedded with claystones. Groundwater is reported at approximately 16 ft bgs and is expected to fluctuate seasonally and perhaps daily given the proximity to the Pacific Ocean.

Aggregate specified on the drawings for the bioretention BMP includes American Association of State Highway and Transportation Officials (AASHTO) #57 stone for the drainage reservoir rock and AASHTO #8 stone for the filter material between the engineered filter media and the reservoir rock. Similar materials should be utilized in the permeable paver BMP. We recommend the permeable paver stones be underlain by 8 inches of #8 stone, followed by 30 inches of #57 stone, for a total aggregate section thickness of 38 inches. The compacted #8 stone will provide both a uniform base for the paving stones and a geotechnical filter for material migration into the #57 stone. The #57 stone should be placed in lifts no greater than 8 inches and compacted using two passes of a smooth drum roller in vibratory mode and two passes in static mode, such that no further vertical deflection is observed on the second static pass. Compaction methods should be monitoring by the field geotechnical representative. It is anticipated the aggregates will be comprised of crushed granitic rock.

---

[1] "NESDI Pilot LID Demonstration Project", Sheets C-0.00, C-1.01, C-1.02, prepared by the Low Impact Development Center, dated 17 July 2015.

[2] "Geotechnical Investigation, Navy Federal Credit Union Branch, Intersection of Main Street and 30th Street San Diego, California", prepared by TerraPacific Consultants, Inc., dated 25 November 2013.

Both BMPs are designed as flow-through facilities and do not require hydraulic isolation from the soil. Although incidental infiltration of storm water into the soil will occur, neither BMP relies upon infiltration as a component of treatment. Moreover, fine grain materials in the fill soil and terrace deposits will constrict the granular pore space in the soil thereby reducing hydraulic conductivity. Soil permeability tests were not included in the referenced geotechnical report, but based on the subsurface conditions described in the report, the infiltration rates are anticipated to be low. Water that does infiltrate will mostly migrate vertically downward, and the 12 to 13 ft separation from groundwater is consistent with local standards and BMP guidelines. Lateral migration of infiltrated water will also be low, and consequently the collateral impacts are anticipated to be limited. For the reasons described above, impermeable geomembrane liners would have limited value and are not recommended for these BMPs.

We appreciate the opportunity to provide this limited geotechnical review of the BMP designs. Please let us know if you require any further information.

Regards,

Ronald S. Johnson, PE, GE
Principal

APPENDIX D

NESDI Pilot Lid Demonstration Project

Submittal

For

Landscape Planting

Revised 4-19-16

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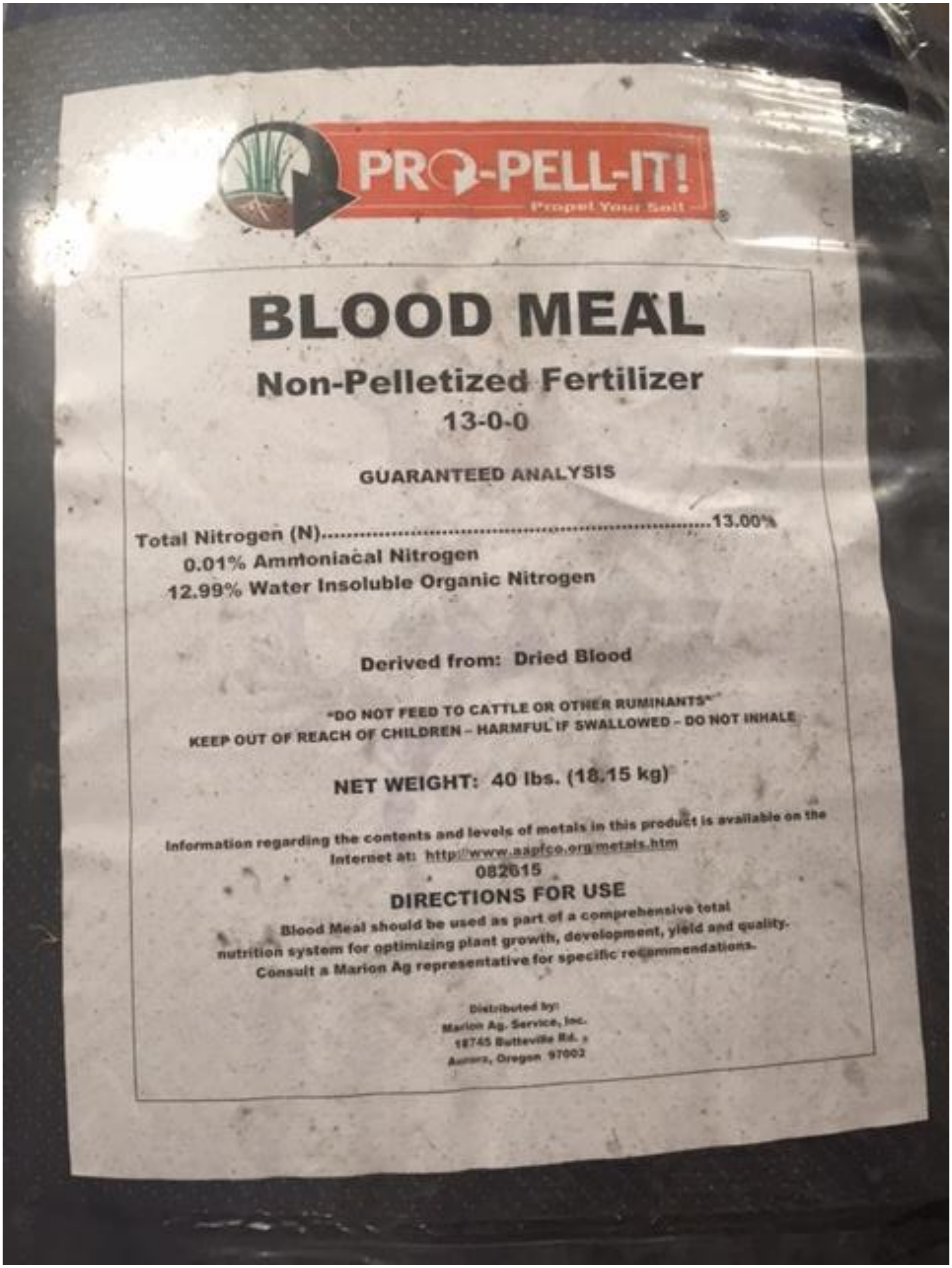

PRO-PELL-IT!
Propel Your Soil
BLOOD MEAL
Non-Pelletized Fertilizer
13-0-0
GUARANTEED ANALYSIS
Total Nitrogen (N)....................13.00%
0.01% Ammoniacal Nitrogen
12.99% Water Insoluble Organic Nitrogen
Derived from: Dried Blood
"DO NOT FEED TO CATTLE OR OTHER RUMINANTS"
KEEP OUT OF REACH OF CHILDREN – HARMFUL IF SWALLOWED – DO NOT INHALE
NET WEIGHT: 40 lbs. (18.15 kg)
Information regarding the contents and levels of metals in this product is available on the Internet at: http://www.aapfco.org/metals.htm
082615
DIRECTIONS FOR USE
Blood Meal should be used as part of a comprehensive total nutrition system for optimizing plant growth, development, yield and quality. Consult a Marion Ag representative for specific recommendations.
Distributed by:
Marion Ag. Service, Inc.
18745 Butteville Rd.,
Aurora, Oregon 97002

Bioswale Mix

AGRISERVICE Quality Parameters

Product Description and Production Benefits Application

- Bioswale Mix is an evenly mixed composition of washed sand, sandy loam topsoil and Humic Compost.
- Particle size is 3/8 inch minus.
- Moisture content at the time of marketing is approximately 10%.
- Bioswale has the following parameters:
    - Sand 50% to 60%
    - Topsoil 20% to 30%
    - Compost 20% to 30%
- Permeability rate and agricultural suitability test results are available on request.
- One cubic yard of Bioswale Mix weighs approximately 2,000-2,200 pounds.

Benefits

- Bioswale Mix provides good drainage and water infiltration to remove silt and pollution from surface runoff water.
- Topsoil and Humic Compost support healthy plant growth for vegetated swales.
- Humic Compost promotes soil conditioning and helps establish active microbial populations to assist plant health and purification of polluted runoff water.

Application

- Use in a swaled drainage course as specified by the project landscape architect or engineer.

Ordering Information

Office: (760) 295-6255 Fax: (760) 295-6262

Mail: 3720 Oceanic Way, Oceanside, CA 92056

Email: orders@agriserviceinc.com

Web: http://www.agriserviceinc.com

WALLACE LABS	**SOILS REPORT**	Print Date	Apr. 27, 2015	Receive Date 4/24/15
365 Coral Circle	Location	Agri Service		
El Segundo, CA 90245	Requester	Mary Matava		
(310) 615-0116	graphic interpretation: * very low, ** low, *** moderate			
ammonium bicarbonate/DTPA		* * * * high, * * * * * very high		
extractable - mg/kg soil	**Sample ID Number**	15-117-04		
Interpretation of data	**Sample Description**	2) Bioswale Mix 65		

Interpretation (low / medium / high)	elements	value	graphic
0 - 7 / 8-15 / over 15	**phosphorus**	32.12	*****
0-60 / 60 -120 / 121-180	**potassium**	225.14	*****
0 - 4 / 4 - 10 / over 10	**iron**	5.84	***
0- 0.5 / 0.6- 1 / over 1	**manganese**	11.94	*****
0 - 1 / 1 - 1.5 / over 1.5	**zinc**	1.94	****
0- 0.2 / 0.3- 0.5 / over 0.5	**copper**	0.38	***
0- 0.2 / 0.2- 0.5 / over 1	**boron**	0.42	***
	calcium	338.22	***
	magnesium	147.12	****
	sodium	139.17	***
	sulfur	41.62	**
	molybdenum	0.02	***
	nickel	0.07	*
The following trace elements may be toxic The degree of toxicity depends upon the pH of the soil, soil texture, organic matter, and the concentrations of the individual elements as well as to their interactions.	**aluminum**	n d	*
	arsenic	0.04	*
	barium	2.53	*
	cadmium	0.02	*
	chromium	n d	*
	cobalt	0.17	*
	lead	0.31	*
	lithium	0.22	*
	mercury	n d	*
	selenium	n d	*
The pH optimum depends upon soil organic matter and clay content- for clay and loam soils: under 5.2 is too acidic 6.5 to 7 is ideal over 8.0 is too alkaline	**silver**	n d	*
	strontium	2.38	*
	tin	n d	*
	vanadium	n d	*

	Saturation Extract	value	graphic / millieq/l
	pH value	7.64	****
The ECe is a measure of the soil salinity:	**ECe (milli- mho/cm)**	2.54	****
1-2 affects a few plants	**calcium**	123.3	6.2
2-4 affects some plants,	**magnesium**	58.6	4.8
> 4 affects many plants.	**sodium**	255.1	11.1
	potassium	98.3	2.5
	cation sum		24.6
problems over 150 ppm	**chloride**	469	13.2
good 20 - 30 ppm	**nitrate as N**	5	0.4
	phosphorus as P	2.6	0.1
toxic over 800	**sulfate as S**	93.7	5.9
	anion sum		19.5
toxic over 1 for many plants	**boron as B**	0.21	**
increasing problems start at 3	**SAR**	4.7	***
est. gypsum requirement-lbs./1000 sq. ft.		24	

infiltration rate inches/hour	9.14	sand - 91.5%
soil texture	sand	silt - 6.4%
lime (calcium carbonate)	no	clay - 2.0%
organic matter	low/fair	
moisture content of soil	3.1%	gravel over 2 mm
half saturation percentage	17.7%	12.8%

Elements are expressed as mg/kg dry soil or mg/l for saturation extract.
pH and ECe are measured in a saturation paste extract. nd means not detected.
Sand, silt, clay and mineral content based on fraction passing a 2 mm screen.

WALLACE LABS
365 Coral Circle
El Segundo, CA 90245
(310) 615-0116

SOILS REPORT

Print Date Sep. 9, 2015 Receive Date 9/8/15

Location Agri Service
Requester Mary Matava

graphic interpretation: * very low, ** low, *** moderate, * * * * high, * * * * * very high

ammonium bicarbonate/DTPA
extractable - mg/kg soil

Interpretation of data (low / medium / high)		Sample ID Number	15-252-10	
		Sample Description	Unamended Topsoil 9/2015	
low	medium / high	**elements**		graphic
0 - 7	8-15 / over 15	**phosphorus**	8.30	***
0-60	60 -120 / 121-180	**potassium**	159.58	****
0 - 4	4 - 10 / over 10	**iron**	13.42	****
0- 0.5	0.6- 1 / over 1	**manganese**	1.29	****
0 - 1	1 - 1.5 / over 1.5	**zinc**	3.90	****
0- 0.2	0.3- 0.5 / over 0.5	**copper**	3.34	*****
0- 0.2	0.2- 0.5 / over 1	**boron**	0.14	**
		calcium	336.88	***
		magnesium	108.89	****
		sodium	139.86	***
		sulfur	43.86	**
		molybdenum	0.07	***
		nickel	0.17	*
The following trace elements may be toxic The degree of toxicity depends upon the pH of the soil, soil texture, organic matter, and the concentrations of the individual elements as well as to their interactions.		**aluminum**	1.45	***
		arsenic	n d	*
		barium	1.01	*
		cadmium	0.03	*
		chromium	n d	*
		cobalt	0.02	*
		lead	3.16	**
		lithium	0.18	*
		mercury	n d	*
		selenium	n d	*
		silver	n d	*
		strontium	2.25	*
		tin	n d	*
		vanadium	0.58	*

	Saturation Extract			
The pH optimum depends upon soil organic matter and clay content- for clay and loam soils: under 5.2 is too acidic 6.5 to 7 is ideal over 8.0 is too alkaline	**pH value**	7.55	****	
The ECe is a measure of the soil salinity:	**ECe (milli-mho/cm)**	1.68	***	millieq/l
1-2 affects a few plants	**calcium**	125.2		6.3
2-4 affects some plants,	**magnesium**	29.1		2.4
> 4 affects many plants.	**sodium**	148.5		6.5
	potassium	13.6		0.3
	cation sum			15.5
problems over 150 ppm	**chloride**	94		2.6
good 20 - 30 ppm	**nitrate as N**	67		4.8
	phosphorus as P	0.3		0.0
toxic over 800	**sulfate as S**	75.8		4.7
	anion sum			12.2
toxic over 1 for many plants	**boron as B**	0.14	*	
increasing problems start at 3	**SAR**	3.1	***	
est. gypsum requirement-lbs./1000 sq. ft.		24		

relative infiltration rate	slow/fair
estimated soil texture	sandy loam
lime (calcium carbonate)	slight
organic matter	low
moisture content of soil	4.7%
half saturation percentage	13.0%

Elements are expressed as mg/kg dry soil or mg/l for saturation extract.
pH and ECe are measured in a saturation paste extract. nd means not detected.
Analytical data determined on soil fraction passing a 2 mm sieve.

7500 Mission Gorge Rd.
San Diego Ca. 92120

Phone: 619-265-0296
Fax: 619-286-1354

SUPERIOR READY MIX

Plant Superior

Material Type WCS PA

Date August 19, 2015

Contractor: Agri-Service

Job:

Material Source PA

Sample From Stock Pile

Tested By James Pratt

Sampled by: James Pratt

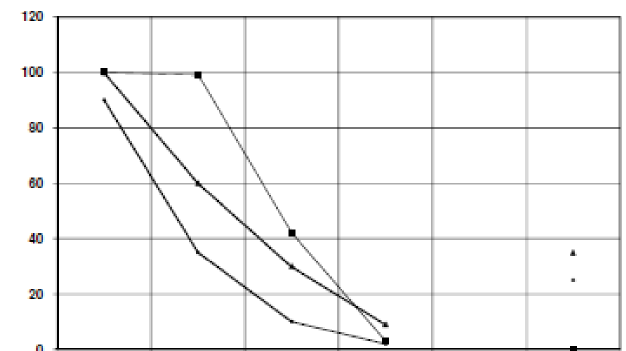
TABLE A:
SIEVE ANALYSIS (ASTM C136), percent passing

Sieve Size	MAT WEIGHT	% PASSING	ASTM C33	
1-1/2"	0	100		
1"	0	100		
3/4"	0	100		
1/2"	0	100		
3/8"	0	100	100	
#4	3	99	95-100	
#8	66	87	80-100	
#16	192	62	50-85	
#30	297	42	25-60	
#50	398	22	5-30	
#100	460	10	0-10	
#200	493	3.0		

SA WET WT	510
SA DRY WT	510
SE WET WT	0
SE DRY WT	0
DIFF	0
%MOIST	#DIV/0!
+#4 WET WT	510
-#4 WET WT	0
-#4 DRY WT	510

Sand Equivalent 75

Test Results



	3/4"	#4	#30	#200		SE
Course	90	35	10	2		25
Base	100	99	42	3.0		0
Fine	100	60	30	9		35

Landscape Blend Mulch

AGRISERVICE Quality Parameters

Product Description and Production Benefits Application

- Landscape Blend Mulch is a natural, medium brown groundcover that knits down to reduce erosion and water loss.
- Landscape Blend Mulch is a blend of Trail Mulch and Forest Fines.
- Feedstock used includes source separated construction lumber, tree wood, tree trimmings and bark.
- Material is ground to produce a typical particle size of less than one inch in diameter and two inches in length. 90% of the product, by volume, conforms to this particle size range.
- One cubic yard of Landscape Blend Mulch weighs approximately 400 to 500 pounds.

Benefits

- Landscape Blend Mulch provides a natural appearance and camouflage for leaf litter.
- Suitable as surface mulch in small or large common areas, parks, trails, native habitat landscaping, residential slope areas and for light foot traffic.
- Fine particles sift down to the soil. As they decompose nutrients and organic matter are incorporated into the soil to increase soil tilth.
- Larger wood particles remain on the surface and breakdown over a longer period of time.
- Holds well on slopes for erosion control.
- Improves water filtration, increases the soil's water holding capacity and creates a nutrient reservoir.
- Suppresses seed germination, which decreases the need for weeding.
- Landscape Blend Mulch is designed to last longer than our Forest Fines Mulch.

Application

- Apply over soil after planting or on existing plantings.
- An application rate of six to nine cubic yards per 1000 square feet is recommended for a two to three inch thick mulch layer.
- Avoid direct contact with plant stems by pulling mulch several inches back from the plant crown or stems.

Ordering Information

Office: (760) 295-6255 Fax: (760) 295-6262 Email: orders@agriserviceinc.com

Mail: 3720 Oceanic Way, Oceanside, CA 92056 Web: http://www.agriserviceinc.com

APPENDIX E

Site and Low Impact Development (LID) Monitoring Recommendations for Naval Base San Diego (NBSD) Commercial Area

Contract # N66001-15-F-0164 CDRK A0001

Date: October 7, 2015

Prepared for:
Energy and Environmental Sciences Group
Space and Naval Systems Warfare Center

Prepared by:
The Low Impact Development Center, Inc.
Robert Pitt, Consultant
Geosyntec Consultants

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1.0 INTRODUCTION

The following report is the monitoring plan that will be used to support the efforts of the Low Impact Development (LID) pilot projects at the Naval Base San Diego (NBSD) Commercial Area. There are two (2) selected pilot project areas and three (3) reference monitoring locations that are identified in the Technology Selection Report (Weinstein and Pitt, 2015). Design build construction plans and specifications are being prepared for the pilot project areas. Both of the areas are designed to treat copper (Cu) and zinc (Zn) that are found in the stormwater runoff from the parking areas. One project area is in front of the existing Naval Exchange. This is a permeable pavement area that will use Interlocking Concrete Permeable (ICP) pavers. The second project area is a bioretention cell that is to be constructed at the existing parking lot to the southwest of the Naval Exchange. The bioretention cell was designed with a specialized media mix that is designed to reduce Cu and Zn concentrations in the stormwater. One reference monitoring location is also in the parking lot with the bioretention cell. It has similar drainage characteristics to the pilot projects. The other two (2) monitoring locations are at the Navy Federal site that is to the east of the Naval Exchange. These monitoring locations will be used to evaluate the effectiveness of a standard bioretention cell design. The locations of the pilot projects and the monitoring locations are identified in Figure 1: Project and Monitoring Locations.

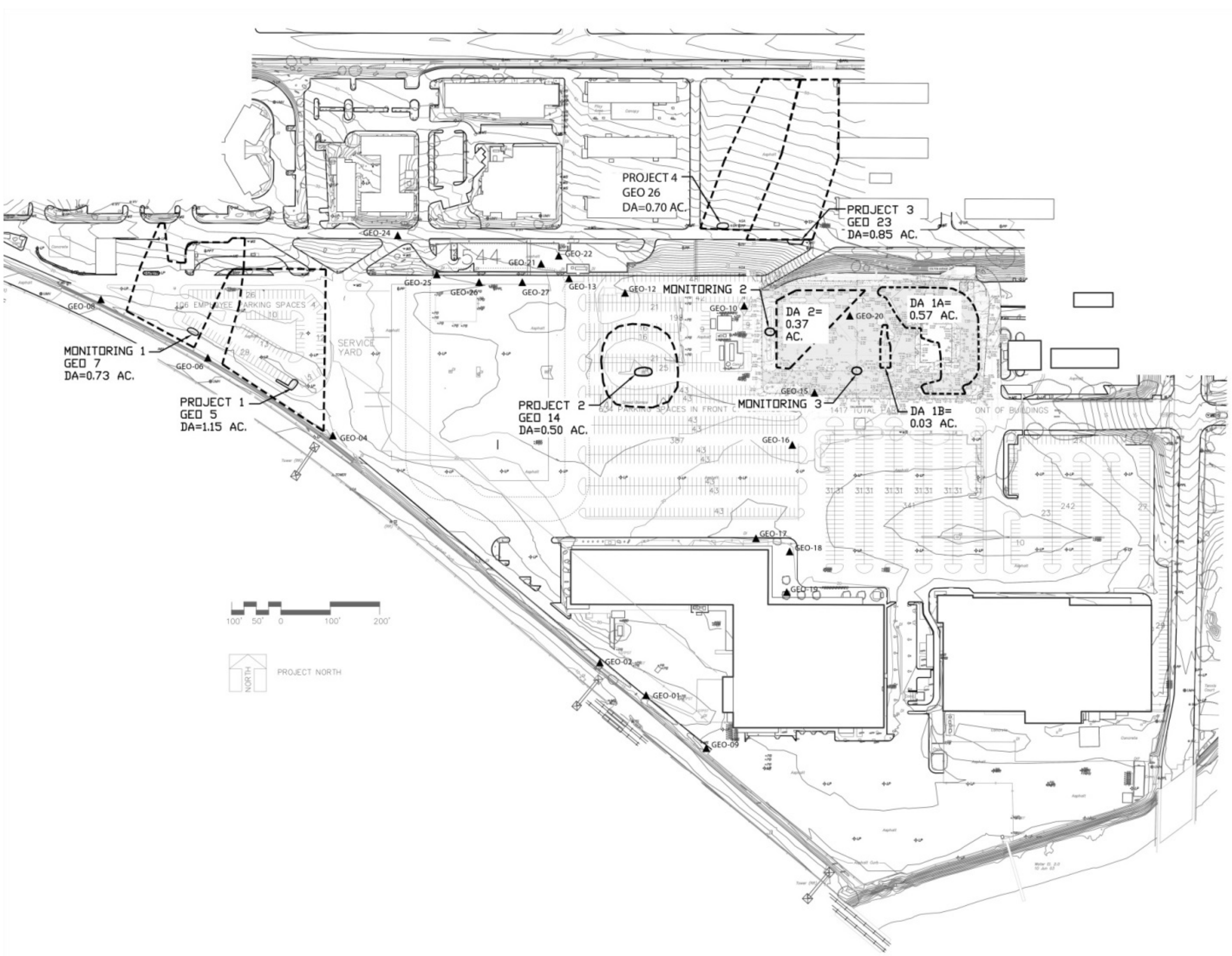

Figure 1: Project and Monitoring Locations

This report includes a brief summary of the suggested protocols and testing procedures that should be used to monitor the pilot projects and the reference monitoring locations. The recommended locations and procedures for monitoring and collecting stormwater runoff samples are also discussed.

2.0 SUGGESTED MONITORING PROTOCOLS AND TESTING PROCEDURES

The purpose of the monitoring effort is to collect data that will be analyzed to determine the effectiveness of individual LID practices at reducing the concentration and loads of copper and zinc in stormwater runoff from commercial areas at NBSD that have high percentages of imperious surfaces, such as rooftops, walkways, and pavements. The data and results of this project are not intended to be used to directly support the current monitoring efforts National Pollutant Discharge Elimination System (NPDES) permits at the installation. Protocols for monitoring and sampling of stormwater for research and acceptance of a device as a stormwater BMP should be used. Detailed information on these is available (Togawa, 2011). Described below are some of the key protocols, procedures, and supporting background information that can be used to develop the final analytical approach in the monitoring plan.

2.1 Determination of Mass Balance of Pollutants and Rainfall

A goal of the monitoring program is to determine the mass balance of zinc and copper as well as the volume and rate of stormwater runoff in relationship to the rainfall events. This requires measurements of the inflow and outflow of stormwater through the LID best management practice (BMP). The inflow can be collected at the entry point to the BMP and the outflow can be measured at the discharge of the underdrain or overflow structure. This will also allow for a determination of the amount of runoff that is collectively evaporated from the surface, infiltrated by the media, and uptaken by the vegetation (evapotranspiration) in a bioretention cell. A mass balance of the relationship between runoff and the losses of runoff through the bioretention cell can then be conducted.

Additional options that were considered, but are not recommended for this effort include monitoring include metal sorption by the media and uptake of pollutants by the plants through the process of evapotranspiration. The monitoring of metal sorption would require the collection of media samples for chemical analysis at the beginning and end of the monitoring period. It is recommended that the media be sampled at six (6) inch depths. The uptake by plants, which in this case would most likely be a minor contribution, would require the separate sampling of roots, leaves, and stalks over the growing season.

Sampling procedures should use flow-proportioned composites (CSUS, 2013). These procedures were developed for use by CALTRANS. According to CSUS, the documented benefits of using flow-proportioned composites over time-proportioned composites or grab samples are:

> "(1) they are not biased by over- or under-sampling on any part of the hydrograph; and (2) they allow direct estimation of Event Mean Concentration (EMC) from analysis of the composite sample, and calculation of Event Mass Load (EML) as the product of the composite sample concentration and the total event runoff volume, without making assumptions about the shape of the hydrograph or the relationship between pollutant concentrations and flow rates.
>
> Flow (i.e., volumetric flow rate) is defined as the volume of water per unit of time that is transported through a designated cross-sectional area. In the context of stormwater monitoring, flow rate is typically measured as the volume of water that passes through a channel or conveyance in gallons per second. Measuring flow accurately is necessary to collect flow-proportioned composites. Flow-proportioned composite sampling requires an estimate of several key parameters, including:

- Storm event Quantity Precipitation Forecast (QPF) (from forecast information)
- Expected runoff volume (determined from the QPF and watershed characteristics)
- Expected storm duration (for even-time-interval methods)
- Minimum required composite sample volume for planned analyses and toxicity tests, including a Toxicity Identification Evaluation (TIE), if applicable
- Minimum acceptable number of sample aliquots"

The document further recommends that an on-site rain gauge is required for precipitation measurement. To determine appropriate rainfall amount per aliquot for a target storm event, simply divide the expected event total flow by the number of sample aliquots required. This is determined by the total composite volume required and the desired sample aliquot volume, subject to the minimum numbers of sample aliquots per event. Burton and Pitt (2002) illustrate how to develop different sampler programs (sampling volume increments) for expected small, intermediate, and large events.

In addition to the flow and precipitation monitoring, it is also recommended that simple stage sensors with a recording device be installed in the stormwater controls to continuously measure water depth in the devices. The recorders should be located at the bottom of vertical perforated pipes extending to the bottom of the excavation depth of the control. These are capable of recording water depth with high resolution (at 5 to 15 minutes) during and between rains. These recorders will directly and continuously measure the infiltration rates and drain down times of water in the controls, assisting with the mass balance calculations and detecting seasonal groundwater problems, or maintenance requirements.

2.2 Water Quality Testing Parameters for Copper and Zinc

The analysis of metals in stormwater runoff requires some distinct and unique tests. The toxic effects of many heavy metals vary as a function of hardness, and the California Toxics Rule (CTR) lists the receiving water quality objectives for most metals as hardness-dependent equations. Whenever testing of metals is included in a monitoring project, hardness must also be included as a monitoring constituent to properly interpret metals results (CSUS, 2013). Additional parameters of pH, hardness, alkalinity, plus filtered and total recoverable forms of the metals should be monitored. The study also found that

> "Water chemistry parameters such as pH, metal ion concentration, the presence of other reactive ligands and metals, ionic strength, and redox potential dictate metal ion speciation within the water column through complexation and oxidation/reduction processes. These processes impact the extent and rates of interaction with particulate matter and the bioavailability of metals."

2.3 Particulate Size Distribution

A determination of the sediment size and particle size distribution entering and leaving the BMP is a critical element of the testing. A study by the National Cooperative Highway Research Program on the measurement and removal of dissolved metals in highly urbanized areas found the following:

> "Metals in stormwater runoff typically adsorb to sediment with smaller sediment often adsorbing more metals (expressed as mass of metals per mass of sediment) than larger particles presumably due to their larger surface area per unit mass. The distribution of metal mass is correlated to the Surface Area (SA) of particles. Also, due to larger settling velocities, a larger fraction of larger sediment is retained by the sedimentation practice. Therefore the fraction of heavy metal removed is typically less than the fraction of sediment removed." (Barrett et. al., 2014).

2.4 SSC (Suspended Sediment Concentration)

One of the most important measures of performance of stormwater controls is the retention of particulate solids. As noted above, many stormwater pollutants are strongly associated with particulates and their concentration has long been a surrogate of stormwater effects and benefits of controls. SSC retention is also a critical measure of the maintenance requirements of LID practices. This can be determined by inflow and outflow measurements of sediments at the facility.

3.0 DESCRIPTION OF MONITORING LOCATIONS AND PROCEDURES

The following is a brief description of the physical features and guidelines for collecting samples at each of the monitoring locations. A topographic survey should be conducted at each of the monitoring locations in order to determine the high points and drainage areas to the monitoring locations. This is because there have been site improvements and geometric changes to the parking areas since the original construction of the facilities in the drainage areas. The monitoring locations are all set at a manhole or a storm drain inlet. The survey should include the inverts and top elevations of all storm drain structures and the upstream and downstream slopes and conditions of pipes to the structures at the monitoring locations. This will allow the monitoring team to estimate the stormwater runoff and storm drain flows so that the monitoring equipment can be properly calibrated.

It is recommended that a rain gauge be installed at the vicinity of the project location and that the gauge be set to record information at five (5) minute intervals. This will allow measurements for short duration and high frequency storm events. An automated sampler that can collect flow data and water quality samplers should be used. Water samples will be collected as composites for the duration of the runoff events with subsamples to be collected according to the flow rates (flow-weighted composite samples). Additional information can be found in a guidance manual on the effects of stormwater for use by watershed managers (Burton and Pitt, 2002).

A Thel-mar or V-notch weir device or an Area/Velocity Sensor can be used to collect outflow data.The water quality sampler can be used with a flow meter that collects flow data from a bubbler tube that measures water depth in the pipes. A simple bubbler requires a control section (weir) in the pipe. This can be done with a Thel-mar or V-notch weir set at the pipe outlet structure when there is a free flowing outfall at the pipe discharge. An area-velocity flow sensor can be used to calculate the flows in the pipes without a control. This will allow the flow data to be used to pace the automatic samplers and to be compared to the rainfall data in order to calibrate and evaluate the inflow and outflow through the system. An area/velocity flow sensor should be used when there is no free flowing outfall or when it is anticipated that the flows will predominately result in the storm drain pipes flowing full and outfalls in the structures will be submerged, or if adverse flow and backwater flows are anticipated.

Reference Monitoring Location One: This is an open storm drain grate that is identified as Geo 7 in Figure One. The inlet is approximately thirty (30) inches deep. A twelve (12) inch pipe flows into and out of the inlet. The pipe is partially crushed at the inlet and outlet. Figure 2: Reference Monitoring Location shows a picture of the location.

Figure 2: Reference Monitoring Location

The upstream drainage area potentially includes a gas station that drains to the upstream inlet at drainage area Geo-8. This could skew the baseline water quality results because of the additional loads of pollutants generated by this "hot spot". It is recommended that the water quality samples be taken at the surface near the grate entrance if the gas station drains to the system. An automated sampler with a tube and peristaltic pump could be set up at the grate perimeter before a rainfall event. Sandbags or wood blocking (non-pressure treated) could be used to temporarily direct and concentrate flows to the tube. Additional flow and/or water quality monitoring could be conducted at the downstream outlet of the pipe. The existing pipe system is crushed or deformed at the entrance and exit to the structure. This would preclude the use of a weir insert without the pipe being repaired. An area/velocity sensor would be appropriate to install on the downstream section of the pipe, although a stage area relationship in the damaged pipe is still needed.

Reference Monitoring Location Two. This monitoring location is at the Navy Federal Site. It is a yard inlet in the middle of a small bioretention cell that has an eight (8) inch pipe entering and leaving the structure. The inlet collects a small portion of the flow from the parking area. The majority of the drainage is from the pipe system that conveys runoff from Drainage Area 1A and 1B. Figure 3: Navy Federal Site is the drainage area and monitoring location plan for this facility. These drainage areas consist of a parking lot, a drive through teller area, and portions of the bank roof. The sampler could be set up in the bioretention cell next to the yard inlet. An area/velocity and a water quality probe could be set up in the downstream section of the outfall pipe to measure inflow and outflow.

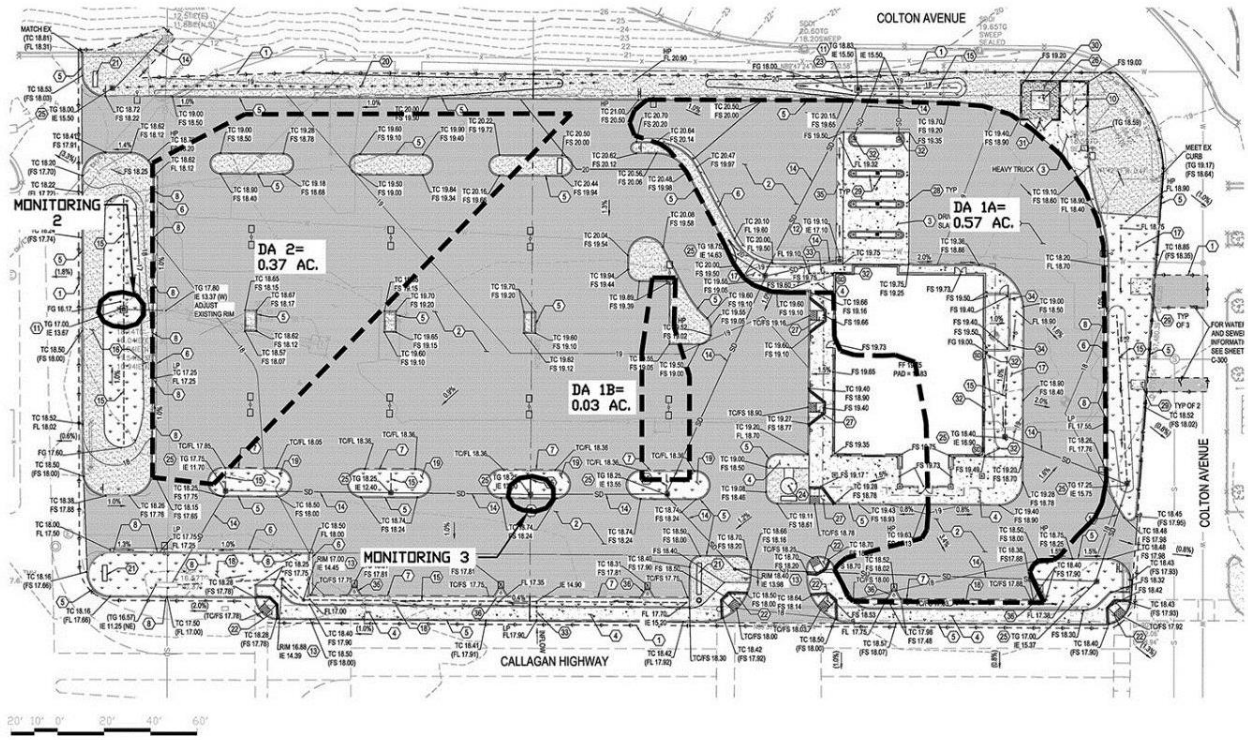

Figure 3: Navy Federal Site

Monitoring Location Three. This location is optional. The media and the drainage design is not controlled through this effort. The information that is collected can be useful to determine how the systems work in non-idealized or controlled conditions. This location is at the bioretention cell that receives runoff from the adjacent parking lot identified as Drainage Area 2. Two (2) underdrains enter the bioretention cell. The flow from the underdrains and the yard inlet discharge to an existing manhole that has a 36 inch storm drain pipe. The inverts of the underdrains are near the top of the storm drain pipe. In periods of large storm events the underdrain system may be inundated from the backwater in the manhole. A hydraulic analysis should be conducted to make this determination. If the flow does not back up into the system at the manhole then a portable weir and flow monitoring system can be used at the outfall of the bioretention system. If backwater is expected, an area-velocity sensor can be used to pace the sampler and to measure flow. No samples should be collected during periods of backwater in the system. This should only occur during large high intensity storm events if the system is adequate.

A four (4) inch diameter PVC well screen with a locking cap could be installed in the bioretention cell media to collect water quality samples from the bioretention media and for installation of a water depth recorder. The specifications for the media should be reviewed and the media should be analyzed to determine its makeup. They are not available at this point in time. The analysis should be a full suite of tests to determine the chemistry of the soil (e.g. pH, phosphorus, organic content, etc.) and the particle size distribution (Leisenring et.al., 2014). The chemistry of any mulch used should also be analyzed. Water quality samples should also be collected from the surface at the curb openings to the bioretention area in order to determine the inflow pollutant loads.

Pilot Project Location One. This is a bioretention cell that collects runoff from drainage area Geo-5. The monitoring location is in a manhole that is located within the facility. Figure 4: Bioretention Project Site Plan shows a plan view of the facility. Figure 5: Project Profile is a profile of the storm drain system and

underdrain for the Bioretention Project. Both of these are preliminary drawings that will be finalized as part of the design build process.

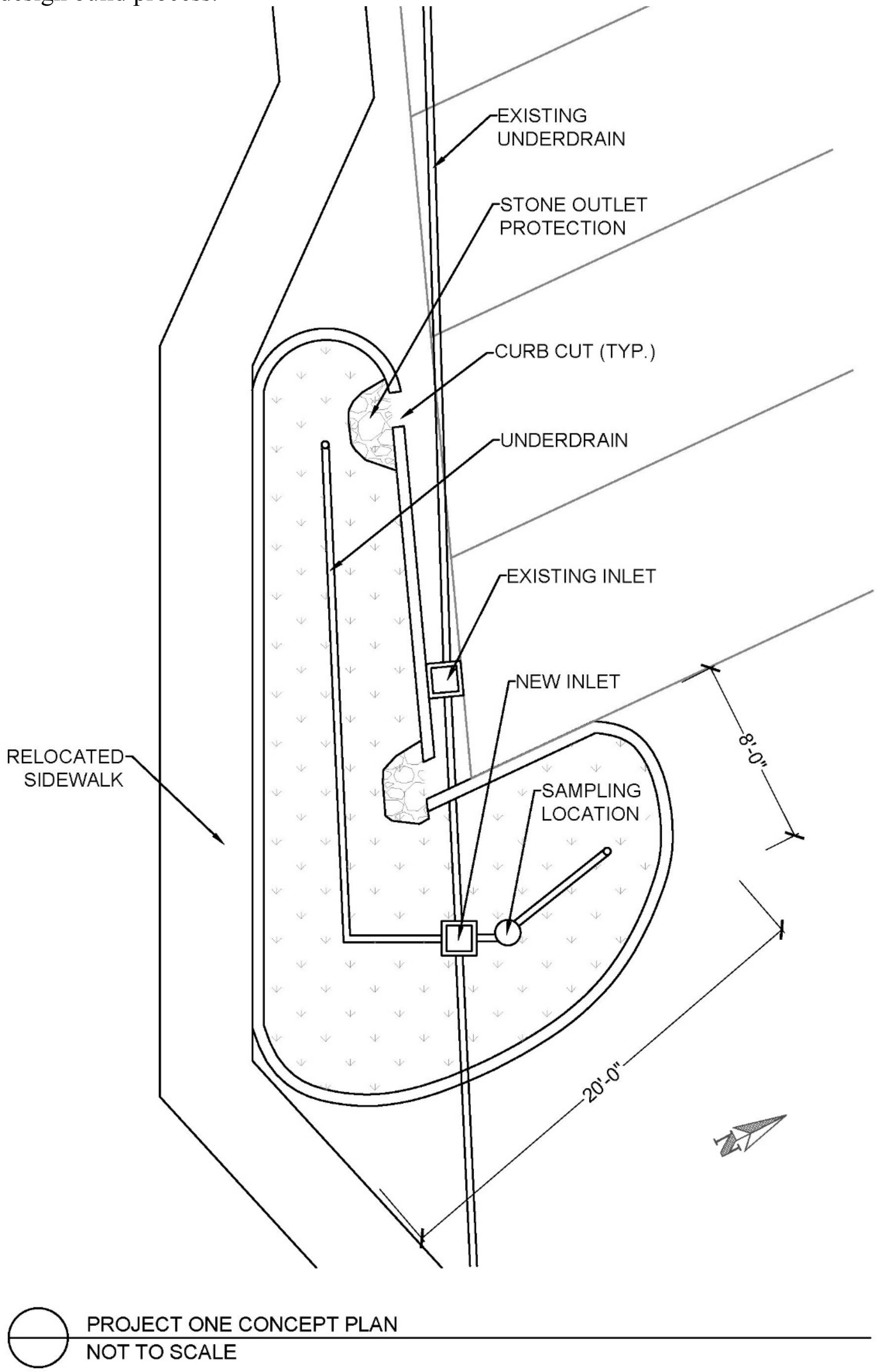

Figure 4: Bioretention Project Site Plan

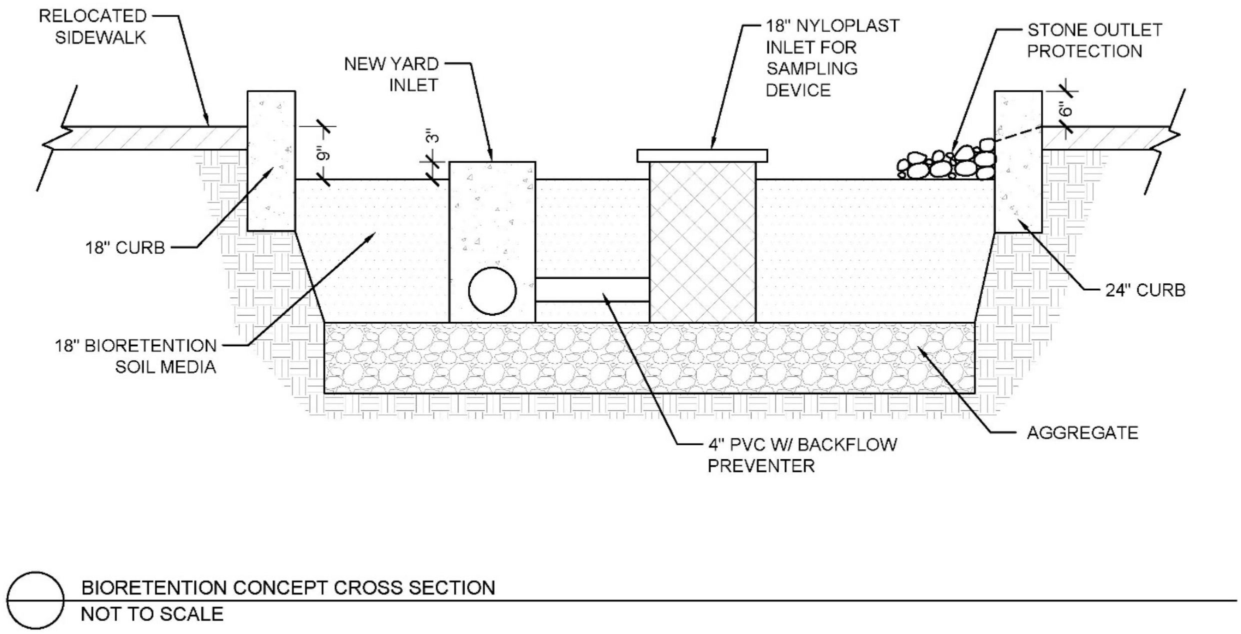

Figure 5: Project Profile

The bioretention area is shallow and the underdrains will most likely be subjected to backwater conditions from the storm drain system. A backflow preventer is installed to prevent potential mixing and contamination of the stormwater from the collection system with the underdrains of the bioretention cells. The backflow preventer is located in the yard inlet and can be removed if the stormwater does not consistently back up into the cell. A well screen should also be installed in the bioretention cell to collect water quality data from the media and to monitor water depth.

Pilot Project Location Two. This is a permeable pavement area that drains to an existing yard inlet in the parking area in front of the Naval Exchange. This area is an interlocking concrete permeable paver installation. The paver blocks are to be located on an existing parking area. An existing grate inlet is located in the central portion of the pavers. The paver underdrains will tie into the inlets. The existing inlet has a depth of approximately 48 inches and a 16 inch pipe enters and leaves the system. The underdrain depth of the permeable pavement should be above the top of the storm drain pipe so that it should not be subject to backwater conditions. This should be confirmed by a hydraulic analysis. Figure 6: Permeable Pavement Area is a site plan of the preliminary design. The dimensions and elevations are subject to change, based on the final design.

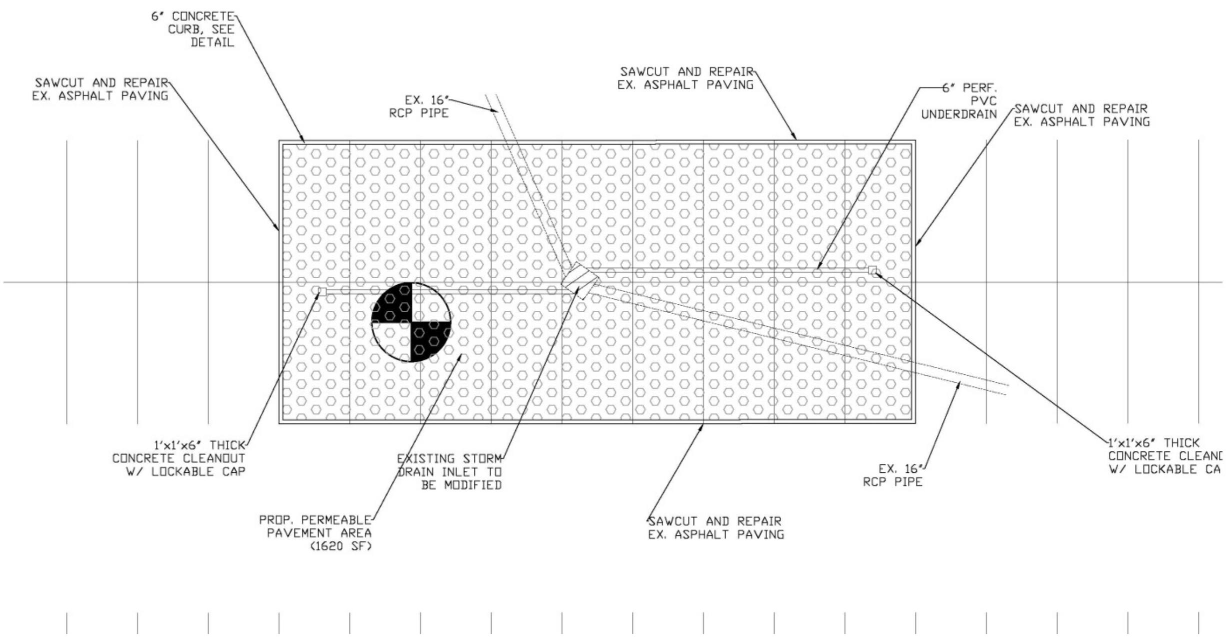

Figure 6: Permeable Pavement Area

A portable weir and monitoring station can be used during storm events. One or two spaces could be marked off and the grate lifted during the event. Water quality samples can also be collected at the edge of the pavement and at the underdrains. It would be difficult to collect influent samples because the area is relatively flat and there are not concentrated flow areas to set up monitoring devices.

4.0 SUMMARY

The following are the key recommendations and summary of monitoring locations and paramaters that are identified in the report. The locations of the sampling and the procedures are:

- Two LID pilot project sites will be monitored. The bioretention cell will include inflow and outflow monitoring/sampling points. The permeable pavement area will be monitored at the outflow location.
- One reference site is recommended in order to determine the representative pollutant load from the parking lots. Optional locations at the Navy Federal site are also identified. These can be used to collect data to determine the effectiveness of bioretention cells that use a standard media mixture that is not specifically developed for the treatment of metals.
- Composite sampling of the influent and effluent will be conducted to determine the efficiency of the systems.
- Composite sampling of Reference site will be conducted to determine effectiveness of LID practices at treating metals whend compared to background or representative pollutant loads.

The key parameters that should be monitored include:

- Rainfall in increments of 5 minutes.
- Flow data that can be used to determine the peak and volume of runoff inflow and the peak and volume of flow from the facility.
- Total and dissolved Cu. Pb, Zn
- TSS and the particle size distribution of solids entering and leaving the facility.

- Particle Size (?)
- Alkalinity and hardness of the runoff and effluent
- pH

REFERENCES

Barrett, M., ., L. Katz, S. Taylor, J. Sansalone, and M. Stevenson. 2014. National Cooperative Highway Research Program (NCHRP) Report 767: Measuring and Removing Dissolved Metals from Stormwater in Highly Urbanized Areas. Transportation Research Board. Washington, D.C.

Burton, G.A. Jr., and R. Pitt. 2002. *Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists, and Engineers*. ISBN 0-87371-924-7. CRC Press, Inc., Boca Raton, FL. 911 pages.

California State University Sacramento (CSUS). 2013. Caltrans Stormwater Monitoring Guidance Manual. State of California Department of Transportation. Sacramento, California

Leisenring, Mark, and Jane Cleary, 2014International Stormwater Best Management Practices (BMP) Database Pollutant Category Statistical Summary Report. Water Environment Research Foundation, Alexandria, Virginia

Togawa, Noburo, 2011, Development and Testing of Protocols for Evaluating Emerging Technologies for the Treatment of Stormwater. The University of Alabama, Tuscaloosa, Alabama.

Weinstein, N., and R. Pitt. 2015. Site and Low Impact Development (LID) Technology Selection for Naval Base San Diego (NBSD) Commercial Area. Space and Naval Warfare Systems Command (SPAWAR). San Diego, California.

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14. ABSTRACT
This report describes an evaluation of the effectiveness of using low impact development (LID) to mitigate stormwater runoff and metal contaminants from Navy commercial areas. The project was conducted at Naval Base San Diego (NBSD) between 2014 and 2017. The work was performed under Project 497 of the Navy's Environmental Sustainability Development to Integration program. The demonstration was completed in response to the need for methods to control stormwater runoff in operational and non-industrial areas of Navy bases requested by Naval Facilities Command Southwest and Northwest Environmental. The NBSD site was chosen for demonstration because it is subject to regulations of stormwater copper, lead, and zinc discharges under its National Pollutant Discharge Elimination System permit and a Total Maximum Daily Load (TMDL) requirement.

The demonstration project successfully evaluated the implementation of LID technology to mitigate stormwater metal contaminants in a naval base commercial area. The outcomes are promising for future implementation at other comparable Navy sites around the country.

15. SUBJECT TERMS
low impact development (LID); stormwater runoff; metal contaminants; Naval Base San Diego (NBSD); Navy's Environmental Sustainability Development to Integration program; copper, lead, and zinc discharges; Total Maximum Daily Load (TMDL)

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